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1903
(lacks some maps)

Commonwealth of Massachusetts.

REPORT OF THE COMMITTEE

ON

CHARLES RIVER DAM

APPOINTED UNDER

RESOLVES OF 1901, CHAPTER 105,

TO CONSIDER THE

ADVISABILITY AND FEASIBILITY OF BUILDING A DAM ACROSS THE CHARLES RIVER AT OR NEAR CRAIGIE BRIDGE.

BOSTON:
WRIGHT & POTTER PRINTING CO., STATE PRINTERS,
18 POST OFFICE SQUARE.
1903.


CHARLES RIVER, BOSTON HARBOR.
AND THE
OPOSED CHARLES RIVER BASIN.
SCALE 2960 FEET PER INCH.
PREPARED TO ACCOMPANY REPORT MADE TO
HENRY L. HIGGINSON, AUGUSTUS HEMENWAY,
JAMES J. STORROW AND OTHERS.
PERCY M. BLAKE,
Civil Engineer.
February 15, 1902.
BORMAY & CO., N.Y.
CERTAIN TIDAL CROSS—SECTIONS
SCALES- HORIZONTAL, 3082 FEET PER INCH
VERTICAL, 29.6 " " "
PROPOSED DEEPENING BY DREDGING TINTED.
MEAN HIGH TIDE
MEAN TIDE
MEAN LOW TIDE
BIRD ISLAND FLATS
WALTHAM
WATERTOWN
UPPER END OF BASIN
NEWTON
CHARLES RIVER
METROPOLITAN SEWER
U.S. ARSENAL
BRIGHTON
SOMERVILLE
CHARLESTOWN
MYSTIC RIVER
MYSTIC WHARF
CHELSEA CREEK
EAST BOSTON
WINTHROP
PROPOSED BASIN
NORTH STATION
STATE HOUSE
OLD BOSTON
SOUTH STATION
CHESTNUT HILL RESERVOIR
BROOKLINE
JAMAICA POND
CHARLES RIVER MEADOWS
STONY BROOK
SOUTH BOSTON
RESERVED CHANNEL
CASTLE ID.
BIRD ID. FLATS
APPLE ID.
GOVERNOR'S ISLAND
PROPOSED 35 FEET CHANNEL
DEER ISLAND
SHIRLEY GUT
PRESIDENT ROADS
PROPOSED 35 FEET CHANNEL
OLD HARBOR POINT
PUMPING STATION
THOMPSON'S ID.
LONG ISLAND
NUBBLE CHANNEL
GALLOP'S ID.
LOVELL'S ISLAND
GEORGE'S ISLAND
RAINSFORD ID.
MOON ID.
SQUANTUM
NANTASKET ROADS
PEDDOCK'S ID.
WINDMILL POINT
U.S. Harbor Line

Committee on Charles River Dam.

HENRY S. PRITCHETT.
SAMUEL M. MANSFIELD.
RICHARD H. DANA.

JOSEPH W. LUND, *Secretary*.
JOHN R. FREEMAN, *Chief Engineer*.

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INTRODUCTION.

As required by Resolves of 1901, chapter 105, this committee submitted its report to the Legislature on Jan. 14, 1903. The work of the committee and of its chief engineer and various experts up to that time had been devoted entirely to collecting information in regard to the feasibility and desirability of the general project, and a mass of data had been accumulated in reference to sewage overflow, harbor conditions and other matters involved in the determination of these general questions, which the chief engineer of the committee has necessarily been several months in reducing to form for publication.

As the mere construction of a dam at Craigie bridge in itself involved no serious engineering difficulties, the committee had made no studies for such a dam, but had largely relied on the reports of the Joint Board of 1894 as a basis for estimates of cost. After the hearings before the joint committee of the Legislature on metropolitan affairs and harbors and public lands, in January, 1903, Mr. Freeman, the chief engineer of the committee, at the request of the commercial interests upon Charles River, made various detailed studies of a dam having a lock with a depth of 18 feet over the sill at low water. The construction of so deep a lock necessitated abandoning the plan proposed by the Joint Board of 1894 of using the lock as a sluiceway, called for the insertion of special sluices, and somewhat increased the expense of the construction of the dam and lock. All these studies and estimates, together with more complete estimates of cost of the marginal conduits and embankment walls, are set forth in Appendix No. 19 to the report of the chief engineer, which presents six plans for a dam, at a cost varying from $983,800 to $1,549,250.

A dam with surface and drawbridge at grade 22, Boston base, will result in frequent interruption of street traffic over the dam, owing to the necessity of opening the draw for all vessels requiring more than 12 feet head room. On this account, with a view to less frequent obstruction of the highway, the chief engineer of the committee recommends a high dam, with a surface and drawbridge at grade 38.5, Boston base, which would allow the passage of tugs and mastless vessels without opening the draw. Studies for such a dam, both of solid masonry and with a steel viaduct, have been prepared, though it is probable that the former is preferable, as the cost of maintenance of a steel structure would offset the decreased expense of construction.

These later studies have resulted in some modification of the figures given on pages 12, 31 and 32 of the report of this committee.

The following is an estimate of the entire cost of the improvement, based on these later estimates: —

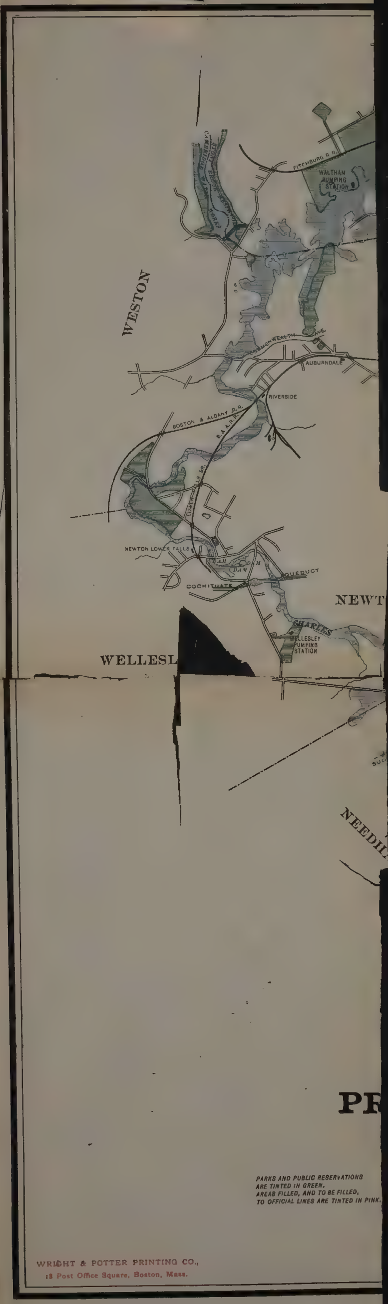
Item No. 1: —	
Dam, elevation 38.5, without catch-basins (estimate of John R. Freeman), ...	$1,425,000
Item No. 2: —	
Marginal conduit, Boston side, Leverett Street to Fens outlet, 11.5 by 10.5 feet (estimate of John R. Freeman),	500,000
Item No. 3: —	
Marginal conduit, Cambridge side (estimate of John R. Freeman), ...	88,000
Item No. 4: —	
Dredging Broad and Lechmere canals, and rebuilding walls (estimate of John R. Freeman and Percy M. Blake), .	100,000
Item No. 5: —	
Dredging in basin (estimate of John R. Freeman), . .	25,000
Item No. 6: —	
Embankment wall and filling, 100 feet wide, Cambridge Street to Fens outlet (estimate of John R. Freeman), 7,550 feet of wall at $20 and 378,000 cubic yards of filling at 60 cents, ...	378,000
Item No. 7: —	
Improvement of Back Street, rear of Beacon Street (estimate of Mr. Jackson), ...	31,350
Item No. 8: —	
Beacon Street sewer, Otter Street to Hereford Street (estimate of Mr. Jackson), ...	60,000

Item No. 9: —		
Extension of Stony Brook conduit from commissioners' channel to the Charles River (estimate of sewer division of street department), ...		$300,000
Item No. 10: —		
Dredging in Fens (estimate of John R. Freeman), . .		50,000
		$2,957,350
Of the total expense, Items Nos. 5, 8, 9 and 10 are for work which is demanded in case a dam is not built, and they amount to . .	$435,000	
Item No. 6, for the embankment from Cambridge Street to the Fenway, is already authorized by Acts of 1893, chapter 435, amounting to	378,000	
Item No. 1: the dam will take the place of Craigie bridge, which must be rebuilt in the near future. The estimate by the city engineer of the cost of a bridge 100 feet wide, with the draw at grade 38.5, Boston base, is	1,463,362	
If the dam is not built, there will be an additional expense in the construction of the wall between Cambridge Street and the Charlesgate East of $45 a linear foot, being the difference between the cost of the Charlesbank wall and of the wall necessary in case the basin is maintained at a constant level of grade 8 (estimate of Mr. Freeman), amounting to	341,000	
		2,617,362
Balance representing total *immediate* increased expenses charged upon the municipalities by this improvement is		$339,988
These figures are based upon one of the most expensive forms of dam, and do not include the future saving on the Metropolitan Park Commission work in the Charles River reservation, in case the dam is built and the water held at grade 8, which is estimated by that commission to be	$425,000	
Or the saving on the sea wall of the Cambridge Esplanade of	37,000	
Or the saving in construction of beach wall on the Cambridge Esplanade of	62,000	
Or saving in cost of filling in the Cambridge marshes of	100,000	
		$624,000

These figures do not include the estimates for dredging the flats in the river to grade — 5, Boston base, as has been suggested, which would entail a total expense of $1,016,945, it being very improbable that so extensive dredging would ever be undertaken; nor do they include the future saving in expense of construction of sea wall between the Fens outlet and the Essex Street bridge.

Taking into consideration the above amount of $624,000, which will be saved in the future to the municipalities bordering on the river, it appears that the treatment of the basin with a dam will effect a saving of $284,012, as compared with the expense of adapting the basin to public use without a dam.

BOSTON, June 1, 1903.



WESTON
CAMBRIDGE WATER WORKS
STONY BROOK RESERVOIR
FITCHBURG R.R.
WALTHAM PUMPING STATION
COMMONWEALTH AVE.
AUBURNDALE
RIVERSIDE
BOSTON & ALBANY R.R.
B.&A.R.R.
LOWER FALLS BR.
NEWTON LOWER FALLS
DAM
DAM
DAM
COCHITUATE
AQUEDUCT
NEWT
CHARLES
WELLESLEY PUMPING STATION
WELLESL
NEEDH
PR
PARKS AND PUBLIC RESERVATIONS ARE TINTED IN GREEN.
AREAS FILLED, AND TO BE FILLED, TO OFFICIAL LINES ARE TINTED IN PINK.
WRIGHT & POTTER PRINTING CO.,
18 Post Office Square, Boston, Mass.

REPORTS

OF THE

COMMITTEE AND CHIEF ENGINEER.

FINANCIAL STATEMENT.

DECEMBER, 1901 — JANUARY 14, 1903.

Appropriation for expenses of committee,			$50,000 00
Stenographer and typewriting,		$1,095 92	
Rent and office supplies, electric light, postage, express, telephone and telegrams, advertising, etc.,		1,876 26	
Maps, plans, photographs, blue-prints,		3,516 92	
Wright & Potter: —			
Printing testimony,	$2,240 29		
Printing report, estimated,	3,500 00		
Printing miscellaneous matter,	111 94		
		5,852 23	
G. W. Field, biologist, report and expenses,		563 46	
Harry W. Clark, chemist, report, expenses and assistants,		1,743 31	
Lieut.-Col. W. A. Jones, United States Corps of Engineers, report and expenses,		673 85	
F. W. Hodgdon, C.E., report and expenses, Broad and Lechmere canals,		220 00	
R. A. Hale, report of flow of upland water, and expenses,		299 24	
Metropolitan Park Commission, for survey of upper basin,		915 82	
Louis F. Cutter, report on separate system of sewerage in Boston, and expenses,		393 22	
J. R. Burke, C.E., harbor survey map,		100 00	
Theobald Smith, M.D., report, assistants and expenses,		716 42	
X. H. Goodnough, sanitary engineer, report and expenses,		777 50	
Prof. W. O. Crosby, geological report,		400 00	
J. R. Freeman, chief engineer, apparatus, boat hire, carpenter work, clerical supplies, labor, etc.,		2,600 72	
J. R. Freeman, services and assistant engineers,		18,460 80	
J. W. Lund, secretary,		3,375 00	
Henry S. Pritchett, Samuel M. Mansfield, R. H. Dana, services and expenses of committee,		6,218 00	
			$49,798 67

Report of the Committee appointed under Resolves of 1901, Chap. 105,

TO CONSIDER THE

ADVISABILITY OF CONSTRUCTING A DAM ACROSS THE CHARLES RIVER BETWEEN THE CITIES OF BOSTON AND CAMBRIDGE.

To the Honorable the Senate and House of Representatives of the Commonwealth in General Court assembled.

Your committee, appointed to report as to the feasibility and desirability of a dam across the Charles River between Boston and Cambridge in the vicinity of the bridges known as Craigie bridge and West Boston bridge, respectfully submits the following statement of its conclusions, together with the reports of the engineers and experts employed by it. The evidence and arguments presented to the committee by those favoring or objecting to a dam are printed in a separate volume, which is submitted herewith.

The work of the committee and the scope of its investigations have been determined by Resolves of 1901, chapter 105, as follows: —

RESOLVE TO PROVIDE FOR THE APPOINTMENT OF A COMMITTEE TO CONSIDER THE ADVISABILITY OF CONSTRUCTING A DAM ACROSS THE CHARLES RIVER BETWEEN THE CITIES OF BOSTON AND CAMBRIDGE.

Resolved, That the governor, with the advice and consent of the council, be authorized and requested to appoint, not later than the thirty-first day of December, nineteen hundred and one, a committee, to consist of three or more suitable persons, one of whom he shall designate as chairman, to investigate and report upon the feasibility and desirability of constructing and maintaining a dam across Charles river between Boston and Cambridge, in the vicinity of the bridges known as Craigie's bridge and West Boston bridge. The committee may employ such assistance as may be necessary, shall give a hearing to all persons desiring to be heard upon the subject, and shall make a report of their doings, with such recommendations as they may deem proper, to the next general court. The committee may expend such sums in the performance of its duties, and shall be allowed such compensation, as the governor and council may determine. The whole expense of the committee shall be borne equally by the cities of Boston

and Cambridge. The powers of the committee shall terminate on the making of their report. If the committee conclude that the proposed dam is feasible and desirable, they shall recommend a plan for apportioning the expense of constructing and maintaining it, between such cities and towns as will specially be benefited by it, and they shall annex to their report the draft of a bill in accordance with their recommendations. The provisions of this resolve shall be accepted by a majority vote of the city councils of Boston and Cambridge before any action can be taken thereunder. [*Approved June 13, 1901.*

Accepted by vote of the city councils of Boston and Cambridge, dated June 24, 1901, and July 3, 1901, respectively.

By Resolves of 1902, chapter 103, the time within which this committee is allowed to report was extended until the second Wednesday of January of the year 1903.

In accordance with the provisions of said resolve, this committee, between Dec. 16, 1901, and July 2, 1902, gave public hearings to all persons desiring to be heard, both in favor of and against the project; and since the close of the hearings, through its own engineers and experts, has investigated as fully as possible all the questions involved.

Your committee was soon convinced that a considerable time would unavoidably be employed in its investigations. When the question of a dam was before the Board of Harbor and Land Commissioners, in 1894, no funds were available to enable that Board to conduct independent examinations. Expert opinions of a widely diverse character were presented in the testimony before that Board, and its report stated: —

The evidence adduced at the hearing in favor of the plan, so far as it affected the harbor, was perhaps necessarily to a large extent desultory and inconclusive. That which was opposed to it was largely expert and other opinion, and recorded observations taken almost if not quite wholly from the reports and data on file in the office of this Board.

That Board made the following suggestion in reference to further investigations which it thought necessary before coming to any conclusion which would justify so radical and permanent a change: —

Bearing in mind that what is suggested to be done may affect the welfare of generations yet unborn for centuries to come, we are met at the outset with the question, What information is necessary to justify the conclusion that so permanent a change can be made without detriment? In order to answer this question understandingly and with certainty, knowledge on the following points is essential: —

1. The exact present condition of the harbor.
2. Just what forces are acting either to improve, maintain or in any way injure it.
3. What effect the proposed lock and dam will have upon these forces.

4. The causes of the shoalings that have from time to time occurred in the harbor, and the material of which they are composed.

5. Whether the natural bottom of the upper harbor is or is not abraded by the currents, and moved from place to place.

Comparative studies should be made of all the plans and records of all general surveys and examinations of Boston harbor and of similar harbors, and to supplement the information thus obtained by further surveys and examinations to cover the portions not sufficiently covered or not covered in sufficient detail, or not at all covered.

A series of observations of the currents should be made; as, since the current measurements were made, in 1861, large areas on the South Boston flats and in Charles, Miller's and Mystic rivers have been filled, and the deep-water channels in the upper harbor have been materially enlarged by dredging.

Physical examinations should be made, by borings or otherwise, and also microscopical and chemical examinations of the material composing the bottom of the harbor to a depth of several feet, especially where the soundings indicate that there has been considerable shoaling, in order to assist in determining the source and amount of all deleterious and foreign substances.

The foregoing data should be collected under the direction of a competent hydraulic engineer, with the assistance of an advisory board of engineers, before any conclusions can be formulated which would justify so radical and permanent a change as is contemplated in the proposed plan.*

Your committee has fully carried out the work thus indicated as a prerequisite to a satisfactory decision, and in the chief engineer's report and the appendices thereto will be found the observations which are here called for.

In addition to these evidently necessary inquiries, the committee has also made a large number of observations in order to settle other questions concerning which the expert opinions given in the evidence before it have differed.

This class of questions may be, perhaps, illustrated by one or two examples.

In the evidence presented for and against the building of a dam there was a wide difference of opinion as to the effect of the salt water in the present basin in cooling the air of the adjacent region during the hot season. One set of experts claimed that this basin was filled twice daily with cool sea water and had a marked influence in lowering the temperature of the air over the city; other experts doubted this effect. The committee dealt with this problem by placing a series of thermometers and thermographs extending from Boston Light to Norumbega Park; thermographs were also placed in different parts of the city. Simultaneous readings of all these instruments were obtained for a period extending through the two and one-half months of

* Report of Board of Harbor and Land Commissioners, 1894, pp. xv and xvi.

summer. The results of these observations were conclusive and final. They showed that the cooling influence of the basin upon the atmosphere of the Back Bay was practically zero.

Another question, and a most important one, concerning which the committee received varying testimony, was that of the quantity of sewage being emptied into the present Charles River basin. Into this subject your committee has endeavored to go with completeness, and an enormous amount of time and work has been spent upon it. As is shown in the reports of experts, and particularly in that of the chief engineer, the sources of pollution are more numerous, and the amount of sewage emptying into the Fenway and thence into the basin is greater, than had been supposed. The present Fenway basin is practically a cesspool; and, without any regard to whether a dam is built or not, this basin should be freed from the objectionable sewage now entering it. A simple and effective method of doing this is shown in the report of the chief engineer.

Similar questions, concerning the effect of a dam upon the health of the region, its effect upon the flow of tides, and many others, could be settled only by a careful and systematic study.

The committee has found it necessary to make extensive surveys. Among these are an accurate hydrographic chart of the Charles River basin, made upon a large scale, and showing with exactness the shoals which have accumulated, and which may need removal; a geological survey of the surroundings of Boston harbor; a survey of the region for the purpose of ascertaining the present sources of malaria, and those which might exist in case the dam were built; and, finally, a survey made from the stand-point of the biologist and bacteriologist. In addition, it has caused to be made a chemical examination of the river water and the material entering the basin.

All of this work has required time, but the committee felt assured that it was desirable to investigate fully all these questions, rather than to leave any of them in an unsettled state; and it believes that the results herein set forth are based upon examinations sufficiently full and accurate to afford safe conclusions. The committee desires to express its obligation to its experts and engineers, and particularly its appreciation of the services of its chief engineer, John R. Freeman, under whose direction the work has been carried on. The committee is also indebted to the Board of Metropolitan Park Commissioners for the completion of that por-

Charles River and Sea Wall in Rear of Brimmer Street, 1902.

Hamburg. Alster Basin. Jungfernstieg.

tion of the survey of Charles River between Essex Street bridge and Watertown dam; and it desires also to express its appreciation of the assistance and cordial co-operation it has received from the members and officers of the Metropolitan Park Commission, the State Board of Health, the Metropolitan Water and Sewerage Board and the Board of Harbor and Land Commissioners; from the officers of the United States Engineers' office and the Navy Yard; and from the officials and engineers of the cities of Boston, Cambridge and Newton and the town of Watertown. All of these boards and officials have given the committee all possible assistance in its studies and investigations.

History of the Project.

The project of building a dam across the Charles River has been discussed since 1859. An act was passed in 1870 providing for the establishment of a Metropolitan Park Commission, for the purpose of improving the basin by a dam, as proposed by the late U. H. Crocker. This act was subject to acceptance by a two-thirds vote of the people of Boston, and was rejected, as only a majority vote was received.

In 1891 Hon. Nathan Matthews, then mayor of Boston, in his inaugural address recommended the creation of a water park out of the basin; and, in view of the private interests involved, suggested that the whole matter be considered by a State commission. The Charles River Improvement Commission was thereupon appointed, under chapter 390 of the Acts of 1891, for the purpose of considering what improvements could be made in the Charles River basin between the dam at Watertown and Charles River bridge at Boston, and submitted two reports, dated Feb. 21, 1892, and April 20, 1893, respectively. Both reports recommended embankments along the river. The second recommended more specifically the discontinuance of the railroad bridges, and their concentration in a new high-level bridge without a draw.

The Legislature of 1893, without acting on these recommendations, appointed a Joint Board, consisting of the Metropolitan Park Commission and the State Board of Health, with instructions "to investigate the sanitary conditions, and prepare plans for the improvement of the bed, shores and waters of the Charles River between the Charles River bridge and the Waltham line on the Charles River, and the removal of any nuisances therefrom." This Joint

Board reported in April of 1894, recommending the building of a dam and lock about 600 feet above Craigie bridge, by which a constant level in the basin would be maintained at about grade 8. The Legislature referred the report of this Board to the Harbor and Land Commission, with directions "to inquire into the construction of a dam and lock in the tidal basin of Charles River, as proposed by the Metropolitan Park Commission and the State Board of Health, sitting as a Joint Board, with special reference to interference with tide water and its effect upon the harbor of Boston."

After holding public hearings, in 1894 the Board of Harbor and Land Commissioners reported that: "This Board is powerless to say, on the imperfect information it has, what effect a dam, as proposed, would have upon shoaling in the upper harbor. Upon all the evidence within the knowledge of the Board, we are unable to find the consequences of building the proposed dam as at all certain of being foreseen; and, in view of the incalculable injury which might ensue from impairing the usefulness of the harbor, we are unable to report in favor of the recommendations contained in the report of the Joint Board." *

By chapter 531 of the Acts of 1898 the Legislature authorized and directed the Metropolitan Park Commission to construct and maintain a dam with suitable locks across the Charles River at or about St. Mary's Street. No action has been taken under this authority.

In 1901 the Legislature authorized the appointment of this committee.

The Present Condition of the Charles River below Watertown Dam, in Relation to the Park Systems of the Cities of Boston, Cambridge and the Metropolitan Park District.

The Charles River basin occupies the centre of the park systems of both Boston and Cambridge and the metropolitan district, and its banks have already been dedicated to the park purposes of these systems.

On the Cambridge side of the river, from Craigie bridge to Watertown dam, the banks of the river, with the exception of about one-half a mile† in a length of nine miles, have

* Report of Board of Harbor and Land Commissioners, 1894, pp. xix, xx.

† Fifteen hundred linear feet are occupied by private interests of the Damon Safe Works, Coleman Brothers and Smith properties, between the Craigie and West Boston bridges; and the entrances to and properties upon Broad and Lechmere canals are also used for commercial and manufacturing purposes. The Hollingsworth & Whitney Paper Companies, Lewando and others occupy 740 feet in Watertown.

Cambridge Embankment and Flats from West Boston Bridge, July 11, 1902. Low Tide at 10 A M. Grade—0.6, Navy Yard = 0, Boston Base.

Flats exposed at Outlet of Fenway, July 11, 1902. Low Tide at Grade 0, Boston Base.
View from Harvard Bridge, Eighth Pier from Boston Side.

been dedicated to the public uses of the Cambridge and metropolitan park systems and the United States arsenal. This is exclusive of the wharves on Broad and Lechmere canals.

Of the beach construction, 5,240 feet are completed, and about 6,540 feet of beach and 2,500 feet of wall remain to be built.

On the Boston side of the river, from the Craigie bridge to the Watertown dam, the banks, with the exception of one mile of private ownership,* have been either occupied or authorized to be occupied for the public purposes of the Charlesbank (the proposed embankment in the rear of Beacon Street authorized by Acts of 1893, chapter 435), by the Bay State Road, and by the Metropolitan Park Commission.

The cities of Boston and Cambridge and the Metropolitan Park Commission have already spent $3,685,000 on these park improvements bordering on the river, and the high-level West Boston bridge, without a draw, is now being built between these cities at a cost of $2,500,000. This, as an architectural and engineering structure, will be in harmony with the general scheme of the use of the river as a park.

Necessary Improvements if no Dam is built.

The Charles River, between the Watertown dam and Craigie bridge, has a mean rise and fall of tide of 9.6 feet, with an extreme predicted range of 13.6 feet, which at times of easterly winds and freshet flow of the river may be increased to 15 feet. In case a dam is not built, it will still be necessary, in order to adapt the river to these park requirements, to dredge the unsightly and unsanitary flats in the lower portion of the river basin to a depth of five feet below mean low water. These flats are indicated upon the survey of the basin made under the direction of this committee. The amount and position of the excavations to be made are indicated in the report of the chief engineer, and their extent and appearance at low tide are shown in the accompanying photographs. In addition, certain changes in the sewage conditions, including separation of objectionable sewage from the Stony Brook channels, extending an overflow channel from the Commissioners' channel to the Charles River, and the interception of the sewage which comes from Beacon Street houses, should be effected; the embankment and walls

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* Costello's Wharf, Cousens' Wharf, 320 linear feet; Brookline Gas Company, 500 linear feet; the Brighton Abattoir, 3,400 linear feet; and the Newton & Watertown Gas Company and others, 1,200 linear feet. (Evidence of Mr. de las Casas, p. 24.)

from West Boston bridge to the westerly line of the Fenway should be built by the Board of Park Commissioners of Boston, in accordance with the provision of the Acts of 1893, chapter 435, with some amendments hereafter suggested; the unimproved banks of the river above the territory which is to be walled must be dealt with in a similar way to that adopted by the Cambridge and metropolitan park commissions above the Boylston Street bridge; and portions of the tidal marshes should be diked, as has been done by the Metropolitan Park Commission between the Boylston Street and Arsenal Street bridges. As the extreme rise and fall of the tide is about 15 feet, these works will be necessarily expensive. The estimated cost of this work above outlined is $3,914,000.*

After this work is completed, however, the river, as a tidal stream, will still for half the time present an unsightly and unattractive appearance. Its use by the public will be limited, and its possibilities as the main feature of the park system will be only partially utilized.

Considerations in Regard to a Dam.

Under the resolves of 1901, your committee is charged with the duty of reporting upon the question of improving these conditions by means of a dam. The resolve directs the committee to report upon three matters involved in the erection of such a structure: —

1. Its feasibility.
2. Its desirability.
3. In case of its feasibility and desirability, to recommend a plan for apportioning the expense of constructing and maintaining it between such cities and towns as will specially be benefited by it, and to annex a draft of a bill in accordance with its recommendations.

Feasibility. — Considered merely as an engineering project, there can be no question as to the feasibility of constructing a dam and of maintaining a basin above it at constant grade, even in times of freshet flow of the river,

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* Cost of sea wall and 70-foot embankment, West Boston Bridge to Fenway, estimate of city engineer, 1894, for park department,	$684,000
Cost of work on Charles River Reservation by Metropolitan Park Commission, including beaching, diking and roads,	1,542,000
Cost of Stony Brook conduit from outlet of Commissioners' channel to river, street department, sewer division (Rep. City Doc. 1901),	300,000
Cost of intercepting sewer in the rear of Beacon Street,	60,000
Cost of dredging flats in the Charles River from the Craigie bridge to 500 feet below Watertown dam to grade —5, estimate by Percy M. Blake, civil engineer,	1,016,000
Cost of wall and beach yet to be constructed by Cambridge Park Commission,	312,000
	$3,914,000

Beach Construction of Metropolitan Park below Arsenal Street Bridge. Low Tide, Dec 18, 1902.

Beach Construction of Metropolitan Park below Arsenal Street Bridge.
View from the River at Low Tide, Dec. 18, 1902.

and this without flooding the Back Bay districts and without obstructing the existing storm sewage overflows.

It will make the following report more clear if it is at once stated that the committee, early in its investigations, was led to believe that, whether such basin were fresh or salt, a dam, if built at all, must be high enough to keep out high tides, and that it must be supplied with a lock for the accommodation of river navigation.

Desirability.—The chief reasons for the construction of such a dam are to be found in the sanitary betterment of the region itself and in the value which such a basin would have in relation to the Boston, Cambridge and metropolitan park systems.

It would be a great addition to the attractions of the city, and would lend itself to a plan of improvement which in the long run cannot fail to make Boston one of the most beautiful cities in the world. The creation of such a basin would give the cities of Boston and Cambridge, practically without expense, an open park area of 1,000 acres, the lower portion of which is situated in the heart of the most congested metropolitan district. How much this basin will be used as a pleasure park, and particularly by the poorer inhabitants of the city, your committee feels itself unable to say. If the use of the Charles River Gymnasium, of the North End Park, of Jamaica Pond and of Franklin Field in the winter is to be taken as a criterion, the basin would be of immense benefit; and there is no reason why such use should not be made of it if rendered accessible and if the use of boats be made easy and cheap. The committee feels that, under reasonable conditions, it ought to become the scene, for at least four or five months of the year, of a great popular playground.

There is no reason why the Charles River below Watertown dam, with the water at a constant level of not less than grade 8, should not offer the same opportunity of use by the public both for a water highway and for purposes of pleasure and recreation which is furnished by the Charles at Riverside, the Thames at Henley and the Alster at Hamburg.

As metropolitan Boston grows passenger traffic ought to develop and reach large proportions on such a stream.

The accompanying photographs of the banks of the river, as improved by the Metropolitan Park Commission, show that with low tides the river at its best offers but little attraction to persons seeking recreation or pleasure upon it or in its vicinity. The currents are too swift for any boat

except racing craft, and the view from the river is generally limited to high banks of rubble or mud. The pictures of the same stretches of the river at the Longfellow marshes and at Lemon brook, with the water at grade 8 and with low tide, show how largely its appearance is dependent on its tidal condition, and a comparison of the photographs of the Alster basin and river frontage at Hamburg with the present views of the rear of Beacon Street and the Cambridge Esplanade gives some idea of the way in which the neglected opportunities of the Charles River basin might be utilized both for the convenience and pleasure of the public and for beautifying the cities of Boston and Cambridge.*

There can be no question that a basin of clear water, held at a constant level, with attractive banks, is in every way desirable. The questions which your committee feels called to answer are: Can this basin be kept reasonably sweet and clean? Can it be maintained with advantage to the sanitary interests of those who live upon the river banks? Will such a basin be prejudicial to the great interests of Boston harbor, or to possible commercial interests in Charles River? And, if these questions can be answered in the affirmative, it then remains to determine whether all this can be done within a limit of cost consistent with a just public policy.

Sanitary Conditions.

The sanitary question is the most difficult, and in some respects the most important, involved in this inquiry, and upon it has been bestowed more time and labor than upon any other question, both by the chief engineer and by experts working independently.

This work has been done in the effort to ascertain, first of all, the quantity and character of sewage actually going

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* The Charles River above the dams is now crowded with pleasure craft in spring, summer and autumn, while below the dams little boating is seen except the racing boats, mostly college ones.

For the difference between swift, tidal waters with exposed flats on the one hand, and a basin of constant level with slight currents on the other hand, in fostering pleasure boating we are not without instructive examples.

After the construction of the half dam at Richmond on the Thames, in England, the use of pleasure boats increased. On the other hand, by the removal of the half dam on the Clyde at Glasgow, Scot., in 1879, on the mistaken theory that this would benefit the harbor by increasing the scour, "a good deal of damage was done to boating, then a popular pastime" (evidence, p. 457); while, on the rebuilding of the weir, lately finished, so as to prevent further damage to the harbor, it is predicted that it will "enable the citizens to enjoy the use of the river for boating."

The Dee Conservancy Board, at Chester, Eng., reported that the dam there, which keeps out the ordinary tides, would, if removed, "ruin the beautiful basin of almost still water, which is immensely enjoyed for boating" (evidence, p. 456).

We have another illustration right at hand. The Cambridge Casino, on the Charles River, near the foot of Hawthorne Street, was furnished with a boat house. At first the boats and canoes were used zealously, but the strong currents and the high, muddy banks, at all times below half tide soon discouraged boating, and later, boating practically ceased. The canoes were all removed, most of them to the upper parts of the river, with constant level and slight currents, though much farther from the owners' homes than the tide water at the Casino.

Longfellow Marshes. Low Tide at Grade 0, Boston Base, Dec. 18, 1902.

Longfellow Marshes. Tide at Grade 8, before building of Speedway.

into the basin, the sources of this sewage and the possible means of its exclusion.

Next, the question of the deposits already made in the basin, from sewage which has been coming into it in the past, was investigated.

Following this inquiry, the experts and engineers of the committee took up the study of the question as to whether fresh or salt water permitted better sanitary conditions; the effect of each upon the bacterial life in the basin was studied, and examinations were made to test, in each case, prevalence of mosquitoes and the consequent effect upon inducing malaria.

These studies of a biological character were accompanied constantly by thorough chemical tests, so that the experts of the committee have endeavored by all scientific methods to study the problems involved in the formation and sanitary maintenance of such a basin from every point of view.

The results of these examinations are found in the series of reports made by the chief engineer and the several experts, and are printed as appendices to this report.

The Present Condition of the Basin.

In considering the question, the present sanitary condition of the basin must be borne in mind. There are in the basin to-day unsanitary conditions, which must be remedied even if a dam is not built.

The Fenway. — The influx of sewage into the Fenway has transformed this body of water from a water park into a drainage canal. The Fens were not offensive as long as Stony Brook discharged through its old channel, in accordance with the original plans of the park department, and the present conditions have been largely caused by the building of the new Commissioners' channel. The present conditions are a nuisance to the people living in the vicinity, and destroy the usefulness and beauty of the Fens as part of the park system. The objectionable sewage at present entering at various points in both the old and new channels of Stony Brook should be removed. The necessity for immediate relief is fully set forth in the report of the street department, sewer division, of the city of Boston for 1901, in which it is proposed to construct a 12-foot channel from the present Commissioners channel to the Charles River, at an expense of $300,000. While this solution of the difficulty will relieve the Fens, it will transfer the trouble to the river basin at the present outlet of the Fens.

The Main Basin.

Direct sewage now enters from the houses on the water side of Beacon Street which should be cut out. There exist in the main basin large areas of flats covered with sewage mud, which are exposed at low tide, and which the Board of Health of the city regard as a "well-recognized public nuisance." These should all be dredged, if there is to be no dam. There is a discharge of the combined overflow sewage in times of storm from the sewerage systems of Boston and Cambridge which should be stopped or curtailed as soon as possible by the introduction of the separate sewerage system, already begun in Cambridge and officially recommended by the sewage division of the street department of the city of Boston in its report for 1901. There are numerous breeding-places for mosquitoes which ought to be removed.

Conclusions.

Basing its conclusions on the study of these conditions and on the reports of its engineer and special experts, the committee finds as follows: —

Fresh water, gallon for gallon, disposes in a normal manner of more sewage than salt water; the tendency of salt water is rapidly to precipitate sewage in sludge at the bottom.

For the proper disposition of sewage in water, it is essential that the water be well supplied with oxygen. This is accomplished by the contact of its surface with the air, and this surface water is carried down by the action of the waves and currents, and especially by the vertical movement caused by changes of temperature. Bodies of fresh, nearly still water are well oxygenated to a depth of 25 feet or more in ordinary summer weather, and to much greater depths with the autumn cold. No considerable part of the basin, with a permanent level at grade 8 or 9, would be over 25 feet in depth.

Letting in salt water under the fresh interferes with the vertical circulation necessary for oxygenation, and the salt water under the fresh soon loses its oxygen if any waste material is admitted into it.

Changing a fresh water basin into a salt from time to time interferes with the bacterial animal and vegetable growths, which effectively aid in taking care of and digesting sewage.

A comparatively still body of fresh water with animal and plant growths will dispose of a considerable amount of sewage admitted from time to time, and will tend to purify itself, even if no more fresh water is added.

Flats exposed at Outlet of Fens Basin, July 11, 1902. Low Tide at Grade 0, Boston Base.
View from Harvard Bridge.

Such a body of fresh water will dispose of more sewage if comparatively still than if in motion.

Most of the sewers in Cambridge and practically all in Boston carry both house sewage and storm water in the same conduits, which are called "combined sewers." These all connect with the intercepting sewers of the metropolitan system on both sides of the river leading into the lower part of Boston harbor; and in dry weather the metropolitan sewers take all the sewage, none of which goes into the basin with the exception of the sewers to the houses on the water side of Beacon Street, and some emptying into Stony Brook which find their way into the Fenway. The metropolitan sewers are not nearly large enough, however, to take both the house sewage and that very much larger body of liquid called the storm water in times of heavy rains and rapidly melting snows; and the surplus of this mixed storm water and house sewage, called the "storm overflow," is emptied into the basin, excepting when the storm water is small in amount.

The amount of house sewage that thus finds its way into the basin is not nearly as great as 7 per cent. of the total volume,* as contended by some authorities. Yet as found by careful measurement and observation it is not safe to assume that, at the dry season of the year, it is less than 3 per cent. of the total. This is somewhat more than supposed by other authorities. The sewers of Watertown, Newton, of parts of Brookline and of a fraction of Cambridge are on the separate plan, in which all rain water is turned into the natural water channels and there are no overflows of house sewage into the river.

Although the amount of fresh water coming over and through the Watertown dam is found by careful measurements to seldom average less than 70 cubic feet per second for the 24 hours in dry seasons, there is good reason to believe this is sometimes reduced to 30 cubic feet a second, for a month at a time, by storage in mill ponds while turbines are shut down.

The water coming over the Watertown dam is well supplied with oxygen, nearly colorless, and, except in the driest weather, nearly fit for a water supply; the only wastes polluting it, and which in dry weather somewhat diminish its purity, are chiefly from factories at Watertown and Waltham, and can be removed.

Notwithstanding the amount of sewage that enters the basin even at present, which our chief engineer estimates as

* The Cambridge sewer clocks have not been relied on as furnishing *final* data, for the reasons stated in the engineer's report.

equivalent to the constant discharge by a population of from 5,000 to 8,000 people, including that which comes from the Fens and from the Beacon Street houses, it is the unanimous opinion of the engineers and experts of the committee that a fresh-water basin, owing to its supply of oxygen and large area, would not affect injuriously the health of the inhabitants in the neighborhood.

Malaria is only spread from person to person by means of the *anopheles* mosquito. This mosquito breeds only in small pools of fresh or partially salt water; it does not breed in a large basin, with properly constructed shores open to the winds, and supplied with fish, even if the water is fresh. There are now, however, many breeding-places of this mosquito on the borders of and near Charles River, which have been located.

It is not true, as has been contended before the committee, that there is a large inflow into the Charles River basin of salt water direct from the ocean twice every twenty-five hours. A study of the currents shows that the water near Harvard bridge at high tide cannot come from the ocean direct, but at the best from the upper middle harbor as it was at the preceding low tide; and this is made up of what came from the Charles and Mystic rivers with the preceding ebb, mixed with what sea water stayed in the eddies and lagoons or was retained between the wharves from the high tide preceding that. A good deal more of the water making up the body of high tide at Harvard bridge comes from points still less remote. In short, the water in the estuary of the Charles surges back and forth day after day, and only gradually finds its way to the sea; the water at high tide near the Harvard bridge is on the average 8 degrees warmer than at Boston Light; when examined bacterially, it is not superior, if it is equal in purity, to the water at the same place at low tide when there is no sewer overflow going on; it is not as pure as the water coming over the Watertown dam.

Examined chemically, the high-tide water at Harvard bridge is somewhat better than the low-tide water; and the incoming sea water at Craigie bridge is about the same chemically as the water at the Watertown dam, except that the latter in summer weather is at present somewhat injured by certain factory wastes, which can be removed, as already stated.

It is not true, as contended, that the salt-water basin, as now existing, lowers the temperature of the air in the territory adjacent to it in warm weather. A most thorough and

long-continued series of tests with recording thermometers has amply proved this. The substitution of fresh water would have no effect upon the temperature of the air, this being controlled by the direction and force of the prevailing winds. The water temperature would undoubtedly be raised from 3 to 4 degrees as shown by the engineer's report.

The level of the ground water in the Back Bay would not be raised by maintaining the level of the proposed basin at grade 8. The building of a tight wall with an embankment behind it, and the construction of a marginal sewer, emptying at grade 6, below the dam, into which some of the ground water could be drained in the immediate vicinity, would probably enable the basin to be maintained at grade 9, should it prove advisable, without interfering in any way with the ground-water level in the Back Bay. The old mill dam under Beacon Street was practically water-tight, and the ground level beyond it seems to be chiefly controlled by leakage into the sewers.

The combined sewers flowing from the Back Bay and from certain of the lower parts of Cambridge, in case of heavy rains during high tide, back up into and overflow the cellars of the houses to an extent that is a constant menace to the residents. If a permanent grade of 8 or 9 were maintained in the basin, this nuisance and danger to health would be removed.

The Fens basin furnishes no criterion for the condition of the large basin, nor of the Fens, if both were maintained as fresh-water basins at a permanent level, even under present conditions of sewer overflow. The Fens basin has far too little fresh water either in it or flowing into it in dry weather properly to care for the amount of sewage and waste admitted. The present circulation of salt water from the Charles River, as now established and carried on, is only about 30 per cent. of what the authorities supposed when they testified at the hearings; and this partially salt water stays under about 2 feet of fresh, loses all its oxygen and rapidly precipitates sewage sludge, which is in a state of fermentation with anaerobic bacteria, and emits nauseous gases. The condition is worse than if no salt water were admitted.

In the main basin the appearance during storm overflows is often worse than the reality, as the turbid fresh water floats over the salt in rather thin layers. If the basin were fresh, that condition would not exist.

With the introduction of the new high-level sewer of the metropolitan system on the Boston side, which will be fin-

ished in less than two years, the amount of sewage entering the basin will be much less than at present.

The Effect of a Dam on Boston Harbor.

In undertaking this study your committee found itself obliged to enter a wide field of investigation.

In the appendices to this report will be found, in the first place, a study of the geological character and history of the harbor and its present condition explained from a geological point of view; secondly, a study of the supposed shoaling and of the existing currents, measured not only at the surface but at various depths, and especially near the bottom; and, lastly, a consideration of the problem from the point of view of modern engineers.

The work suggested by the Board of Harbor and Land Commissioners in their report of 1894 as necessary for a proper determination of the questions involved has been carried out.

First, it may be said that Boston harbor has no sand bars and hooks at its entrance, like New York harbor and almost all the other harbors farther south. The Broad Sound bar through which an entrance is soon to be dredged, is composed of clay, sand, gravel and boulders; and the sand beaches in Massachusetts Bay, both north and south, are in coves with rocky headlands. Arguments drawn from sandy harbors are, therefore, not applicable to that of Boston.

Sand from the submerged drumlins and the islands of the lower harbor, which were formerly being washed away into the surrounding water, but are now practically all guarded by stone structures built by the United States government, no longer comes in as formerly.

In going on with the study of this problem more in detail, the committee found itself face to face with a long-accepted theory of the maintenance of Boston harbor, which, in the end, it has felt obliged to reject.

This theory was accepted by the United States Commission on Boston Harbor, which, from 1859 to 1866, made ten reports to the city of Boston on this subject. The theory adopted was that of the so-called "tidal scour;" and under it improvement of the harbor should be so conducted as to maintain and even increase the tidal prism in reserve, the action of which was supposed to be necessary to maintain the depth of the channels in the harbor.

In 1866, when the last of these reports was made, Boston harbor was still a natural one, with practically no improve-

ment by way of dredging. There were portions of the upper main ship channel which "had a least depth of 18 feet at mean low water, with a least width of 100 feet;" * and in 1894, when the Board of Harbor and Land Commissioners made its report, there were portions of the channel with a minimum depth of 23 feet and a least width of 625 feet.

The present project of the United States government, that of 1902, under which work is now being conducted and for which appropriations have been made, includes the making of a new entrance to Boston harbor across the bar of Broad Sound, 1,500 feet wide, with a minimum depth of 35 feet at mean low water, and a channel thence to the Navy Yard, with a minimum width of 1,200 feet and the same minimum depth.

For the future, Boston harbor will be an artificial one. The great extent of the dredging already done and proposed in the main ship channel, in comparison with the undredged area, is clearly shown on a map annexed. The natural conditions have been so altered by dredging that such equilibrium of forces as maintained the original channels has been entirely destroyed.

The modern steam dredge, the air drill and high explosives have so increased the efficiency and diminished the cost of labor that engineers can now accomplish more than could have been done in 1866. The shoaling, then feared, would no longer be an irreparable injury. The wealth of the community and the value of its commercial and wharf interests are so great as to have completely changed the relation of the harbor dredging to shore improvements.

While these considerations are quite enough to lead your committee to believe that it is no longer necessary to maintain the tidal reservoirs intact, yet it deems it its duty to consider further the original theory of tidal scour, as presented by the commission of 1859–66.

The commission of 1859–66 advanced the fundamental theory that: "Were these reservoirs [the basins of the Charles and Mystic rivers and Chelsea Creek] closed, the larger part of this main artery [the ship channel of Boston upper harbor] would in the course of time cease to exist, for it is but the trench dug through the yielding bed of the harbor by the passage to and fro of the river and tidal waters." (Tenth report, Boston City Document No. 50, 1866, p. 50.) This statement is quoted in the report of the Board of Harbor and Land Commissioners of 1894.

* Report of Chief of Engineers, U. S. A., 1902, p. 98.

That fundamental theory, once adopted, naturally affected the conclusions of the United States Commission. That theory, however, we find to be wholly erroneous.

It is now clearly shown that the main channels of Boston harbor did not originate from the scour of the tidal waters, but are valleys eroded by the rivers in the broad, deep deposit of blue clay laid down near the close of the glacial epoch, when the land was higher than now, and since submerged during the slow subsidence of all this district. These rivers were then much larger than now, owing to the melting snow and ice on the retreat of the glaciers. In other words, the harbor channels are strictly what may be called a series of drowned valleys.

It is important to note that the conclusions of the United States Commission as to the scour in Boston harbor rested largely upon the experiments of the Dutch engineer, Dubuat, made in 1780. These experiments were carried on in a wooden channel 18 inches wide, with water less than 1 foot deep, and are of little significance when extended to large streams or large channels acting upon natural compact materials.*

The Board of Harbor and Land Commissioners, in the report of 1894, p. xvii, also seem to have followed the United States Commission, for they say: "From these [current observations] it appears that the velocities of ebb and flood currents rarely exceed 1 mile an hour between Boston and East Boston. According to Dubuat, a velocity of .15 of a mile an hour is 'sufficient to remove clay fit for pottery,' with which the stiff clays forming the natural bed of portions of the harbor are classed."

The velocity of currents necessary for erosion in natural conditions, as found by the engineer of the committee and by Mr. Hiram F. Mills, in actual practice are much greater than the velocities given by Dubuat.

In this matter we are not entirely dependent upon theory. The bottom of Boston harbor is covered with an average depth of from 6 inches to 5 feet of light, sandy mud. This appears everywhere excepting where dredging has taken place, showing that the currents are too feeble even to erode this softer material enough to leave bare the original hard bottom. The Board of Harbor and Land Commissioners, in their report in 1895, say: —

"Out in the harbor all the material dredged excepting the places at the mouth of the Charles River previously

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* Dubuat himself suggests this difference, which suggestion both the commission of 1866 and the Harbor and Land Commissioners of 1894 seem to have overlooked.

described in the report has been sand, clay, gravel or hard-pan. The channels so dredged maintain their depths, and it has not been necessary to redredge them except in two cases. . . . In almost every case where dredging is done in the harbor, there is found on the surface a black deposit of varying thickness, but not exceeding one foot." (Sen. Doc. 303, 1895.)

It is important to note that tidal scour is an advantage only when under exactly the right conditions. There are well-known instances of harbors with little or no tide or river currents that have maintained their depths far better than other harbors with strong currents. Whatever is eroded from one place finds lodgment in another, and the place of settlement often turns out to be in some of the broader parts of the lower harbor, or at its mouth.

An instance of this appears in the case of the Clyde at Glasgow. The old weir or half dam in the upper reaches was removed in 1879 for the express purpose of benefiting the harbor by increasing the scour. It worked so badly and caused so much damage and expense that the weir has been rebuilt solely for the purpose of preventing the damage that was being done to the harbor by currents (see evidence, p. 457).

The Thames Conservancy Board predicted, about eight years ago, that the half dam, then about to be built at Richmond, and which would cut off a large part of the tidal prism, would result in serious shoaling below. That Board now states "Its effect upon the régime of the river as a whole cannot be said to be injurious" (see evidence, pp. 384, 385).

The Charles and Mystic rivers are not silt-bearing streams, and what little silt may be found in the lower Charles, from street wash and the like, will be kept out of the harbor by the settling basin formed by building the dam.

Mystic Lake, near the mouth of the Mystic River, is deeper than any part of Boston harbor. That it has maintained this great depth is clear proof of the small amount of silt that has come from the river.

The Board of Harbor and Land Commissioners, in their report of 1894, called attention to the apparent deepening of Boston harbor between 1835 and 1861, and the apparent shoaling from 1861 to 1892, during which period the tidal reservoir was so greatly reduced by the filling in of the Back Bay (pp. xvii, xviii, report of 1894).

That there has been no such shoaling is conclusively proved by borings which this committee has caused to be

made, at places where this shoaling is supposed to have taken place; and the samples show the ancient mud, hereafter spoken of, at less than the average depth in Boston harbor, overlying the old clays dating from the end of the glacial period; and this notwithstanding that the tidal prism of the harbor above Governor's Island has been greatly diminished.

Geological observations show that the accumulated silt or sandy mud, so universal on the bottom of Boston harbor, is very ancient, covering in its growth climatic changes and changes in the level of Boston harbor shown by the presence of varieties of shells no longer living north of Cape Cod, and the interstratification of this silt with peat in the surrounding territory. That the process of accumulation is very slow is shown by the estimate that it has taken five thousand years to gather together from 2 to 5 feet, and there has been no tendency to wash any of this out to sea by the action of the currents at the bottom.

Another most important theory, on which the commission of 1859–66 based its report, is that of the "seaward gain" of the currents in the harbor. In the tenth report, p. 52, also cited in the report of the Board of Harbor and Land Commissioners in 1894, it is said: "A grain of sand would daily make two journeys, one up river, represented by 3.15 hours, in which velocity exceeded .3 mile per hour, the other seaward, by 5.18. The seaward gain is therefore fully in the proportion of 5 to 3; there is, then, at this point power sufficient to keep the channel free. . . . Except for the tides hurrying through this avenue to and from the basin above, the present good depth of water could not be maintained."

It is true there is a seaward gain of the currents as measured near the surface, though the proportion of 5 to 3 is not established by any current measurements recorded by that commission or that we find now, nor by any excess caused by the fresh-water flow of the river, called "back water," of which we now have accurate measurements not known to the earlier commission. But, measured from the bottom, where the erosion takes place, the gain is not seaward, but landward. This seems to be explained by the fact that, with a flood tide, the cold and heavier salt water dips under the warmer and brackish water and keeps nearer the bottom. (See chart of current curves in the appendices to the engineer's report.)

It is due to the United States commission of 1859–66 to say that at the time of their report physical data were

very incomplete, the glacial theory had not been developed, and instruments of measurement were far less accurate than at present. It is not surprising, therefore, that this commission, reporting nearly forty years ago, should have been led into a wrong hypothesis as to the origin of Boston harbor.

Your committee has gone into this whole question with the conviction that no enterprise should be undertaken in Boston or vicinity that would affect in any unfavorable manner the future of Boston harbor. It believes that this great harbor is a vital factor in the commercial development, not of Boston and Massachusetts alone, but of the whole country; but it feels convinced that benefit rather than harm will come to the harbor from the erection of a dam, and that, should any shoaling occur, it will be small and of light material, and can easily be removed under the modern methods of dredging at small expense.

Commercial Interests.

The traffic on the Charles River in the delivery of coal and other material, either to wharves upon the river itself or upon the canals in Cambridge, is one that your committee feels should be preserved, whether this traffic is at present large or small, or whether it is increasing or diminishing.

The construction of a dam with a proper system of locks and with such dredging as is indicated below will, in the judgment of the committee, rather facilitate than hinder this traffic. The formation of ice in the winter will be a possible objection, and an estimate of the probable expenditure necessary to protect the annual traffic has been prepared.

In view of the recommendation of the Craigie bridge as the site of the dam, the committee has considered the need of sufficient room for manœuvering vessels between that bridge and the Lowell Railroad freight bridge, immediately below. The evidence submitted to the committee is that a space of 320 feet is necessary, and the committee finds that the requisite space can be obtained by moving the Boston & Maine Railroad freight bridge slightly to the east, and recommends that 400 feet be secured, if practicable.

As the railroad company is under contract with the federal government to renew its present pile bridges with modern structures at an early day, the committee recommends that the railroad be required to locate their new bridges in such a manner as to give the requisite space.

Counsel for property owners on Broad and Lechmere

canals have submitted to the committee a stipulation of certain conditions which they regard as essential, with reference to the size of the locks, dredging the canals, the maintenance of the sea-walls on the canals, and maintaining the canals free from ice in the winter. These conditions, so far as they refer to free maintenance of locks large enough to accommodate the largest vessels which will be used on the Charles, and the maintenance of access to the canals free from ice, should be complied with; and, in consideration of the possible future development of commerce, the committee would recommend locks of even greater width than those suggested by the engineers of the proprietors.

The Broad canal is owned by the proprietors of the banks as tenants in common under an agreement dated in 1806, by which they are authorized to maintain a canal at a depth of 9 feet, and they undoubtedly have certain riparian rights of access to tide water. Any act authorizing the building of a dam should contain a provision that the owners of private property on the river above the dam should recover damages for any injury occasioned to their property by reason of the construction of a dam and the consequent reduction of the water level. It is the opinion of the committee, and also of those interested in the river traffic whose testimony is before the committee, that the maintenance of a permanent water level at the elevation of mean high tide would be a material benefit to owners of wharf property above the dam.

If the basin is maintained at grade 8, Boston base, a depth equivalent to the present mean high water can be obtained by a moderate amount of dredging in the canals, and probably with comparatively small expense for strengthening the walls. The walls along these canals were in most cases built about twenty years ago, and in many places are ruinous, and must soon be rebuilt at the owner's expense. It is probable that the dredging of the canal to the depth called for by the owners at the wharves will result in many cases in causing these walls to fall in. The cost of dredging and rebuilding these walls and dikes, as might be called for under a strict construction of the owners' demands, is estimated by Mr. Hodgdon to be $331,735. In view of the benefit which these canals will receive by having a constant water level, and of the fact that walls will in many cases require rebuilding at an early date, the committee feels that the stipulation by the owners of these premises, if fully complied with, would place them in a much better position than they now enjoy. Dredging these

Lechmere Canal, above Sawyer's Lumber Wharf, Nov. 14, 1902.

Broad Canal, between Sixth Street and Railroad, Nov. 24, 1902. Low Tide at 12.10 P.M. Grade + .64, Boston Base.

canals in the manner proposed by Mr. Hodgdon in his report, p. 423, with the riprapping of the slopes, would leave the canals in as serviceable condition as they now are at mean high tides, and this can be done at an expense of $40,000, for work in the canals, which seems to the committee an equitable adjustment of the claim. A moderate amount of additional dredging in the basin would be required. The cost of this would not exceed $25,000. It was stated by counsel for the owners that $80,000 would probably cover the cost of their requirements. An examination of the photographs which accompany this report, showing the condition of these canals at low water, will give some idea of the limitations placed upon commerce in these canals under present tidal conditions.*

Recommendations.

The committee recommends that a dam be built, sufficiently high to keep out all tides; and that a fresh-water basin be maintained at a permanent level not below grade

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* The maintenance of a level at grade 8, Boston base, would be a reduction from mean high water level of 2.2 feet. Boston base is .64 feet below mean low water at the Navy Yard. Predicted high tides at Boston Navy Yard in 1902 ranged from 7.7 to 11.6 feet above mean low-water level, the mean rise of tide in Charles River being 9.6 feet above mean low-water level, which is a rise equivalent to grade 10.24, Boston base.

The owners of property on the Broad and Lechmere canals in their stipulations request that, in case a dam is built, these canals should be dredged so as to give them a *permanent* depth, with the water at grade 8, which would be from 1 to 2 feet deeper in the channels and from 4 to 7 feet deeper at the wharves than the depth which they have at present upon *spring* tides of 11 feet; and they also ask to be paid for the rebuilding of the walls, which may be necessitated by dredging for obtaining this increased depth. Spring tides of 11 feet occur monthly. The highest predicted tides of 11.5 feet in 1902 occur about four times during the year, and at such times, for a period of three or four days, the rise of the tide ranges from 11 to 11.5 or 11.6 feet.

The stipulation of the owners of property on Broad canal requests dredging which would give a constant water level "between the river and the Third Street draw, *to and at the wharves*, of 18 feet, between the Third and Sixth Street draws of not less than 14 feet, above the Sixth Street draw to the railroad draw of not less than 12 feet, and above the railroad draw of not less than 10 feet."

The owners of property on Lechmere canal stipulate for dredging which will give a constant depth of 18 feet up to Sawyer's lumber wharf and 14 feet above that point.

Under present conditions, with a spring tide of 11 feet, Broad canal, between the Charles River and the Third Street draw, has a greatest depth of 16.6 feet in the middle of the channel, with from 11.6 to 13.6 feet at the wharves; between Third and Sixth streets it has a greatest depth of 12.6 feet in the channel, with from 8.6 to 10.6 feet at the wharves; between Sixth Street and the railroad it has a depth of 11.6 feet in the channel and from 6.6 to 8.6 feet at the wharves; above the railroad it has a depth of 5 feet in the channel, and the canal is being used as a dump.

Lechmere canal, with a spring tide of 11 feet, has a depth of from 12.6 to 15.6 feet in the channel and from 10.6 to 11.6 feet at the wharves up to Sawyer's lumber wharf; above Sawyer's lumber wharf it has a depth of 12.6 feet in the channel, with from 10.6 to 11.6 feet at the wharves.

While owners may intend to dock vessels on spring tides, they cannot take advantage of this to its full extent, as vessels are often detained by head winds and otherwise, and the tides may be held below their predicted height by west winds or other causes.

The dredging stipulated for, nevertheless, calls for a constant depth which *is greater than that now existing upon spring tides of 11 feet, as follows:* Broad canal, between the river and Third Street, in the channel 1.4 feet and at the wharves from 4.4 to 6.4 feet; betweenThird and Sixth streets, in the channel 1.4 feet and at the wharves from 3.4 to 5.4 feet; between Sixth Street and the railroad, in the channel .4 of a foot and at the wharves from 3.6 to 5.6 feet; above the railroad, 4.4 feet. Lechmere canal, in the channel up to Sawyer's lumber wharf, from 2.4 to 5.4 feet and at the wharves from 6.4 to 7.4 feet; above Sawyer's lumber wharf, in the channel 1.4 feet and at the wharves from 2.4 to 3.4 feet.

These depths are taken from the soundings on Broad and Lechmere canals, as shown in map annexed to the engineer's report, and the tide ranges are taken from the tide tables of the United States Coast and Geodetic Survey of 1902.

8 or above grade 9. As this basin is to be used for park purposes, it is essential that the condition of the water should not only be harmless to health, but also that there should be no suggestion of sewage; that the water be as pure as reasonably possible, and thus both the factor of sanitary safety and the enjoyment of the water park be increased. Therefore, the committee recommends that certain changes be made in the present systems, which can be done at reasonable expense, and that the following changes be made conditions precedent to the building of the dam.

First. — That, in accordance with the recommendations of the engineer, all direct sewage and factory waste be taken out of the Stony Brook channel and out of the Charles River between Waltham and Craigie bridge; that the connection between the new Stony Brook channel and the old Stony Brook channel and gate house in the Fens be constructed, and that the old Stony Brook conduit be rebuilt, the cost of both being $347,000, or, in the alternative, that the 12-foot conduit recommended in the report of the sewer division of the street department of 1901, between the mouth of the Commissioners' channel and Stony Brook and Charles River, be constructed, the expense of which is estimated at $300,000. The committee also accepts the recommendation of the engineer that the Commissioners' channel of Stony Brook be extended to Forest Hills, and that the extension of the deep common sewer to Forest Hills be built.

Second. — That a marginal conduit be built, as described in the engineer's report, from the mouth of the Fenway, and preferably from the overflow outlet of the St. Mary's Street sewer, to a point below the dam. The structure recommended by the engineer is about 16 feet in width by 13 feet in depth, and would probably be sufficient to convey the entire flow of Stony Brook and the storm overflow from all of the neighboring sewers in all but the one or two worst storms of the average year except during the hours of extreme high water.

It would be provided with tide gates at its outlet, and in moderate storms its capacity would serve to store the flow entering until the tide had fallen. In heavy storms at extreme high water the surplus will overflow into the basin through numerous channels designed to diffuse the discharge at many points below the surface and to take their flow at or near mid depth of the conduit and thus reject the floating material and also the heavier particles.

It will be a simple matter at any future time to add a propeller pump at the outlet, operated from the same power

plant which works the drawbridge and the lock gates, by which the marginal conduit can be discharged in the hours of extreme tide.

This marginal conduit should be constructed at the same time with embankment already authorized by statute in the rear of Brimmer and Beacon streets, thus saving considerable expense in construction. It would discharge below the dam. On the Cambridge side the overflow channel from Binney Street should, as proposed by the engineer of the committee, be continued below the dam, which is a distance of about 2,000 feet, with similar arrangements for discharge. This would take care of sewage overflow and street wash from 33 per cent. in area and 58 per cent. of the population of Cambridge, the sewage from which at present overflows into the Charles River above Craigie bridge. The marginal conduit on the Boston side connecting with the channel in the Fens would furnish a perfect gravity circulation of fresh water for the Fens in dry weather, the water flowing from the main basin into the Fens to the farther end of the channel and through it and the marginal conduit to a point below the dam whenever the tide outside is not above grade 6. In a similar way a gravity circulation for the Broad and Lechmere canals should be furnished by a connection with the Binney Street overflow conduit.

Third. — The existing deposits of sludge, which at present fill about one-quarter of the cubic capacity of the Fens intended to be filled with water, should be dredged, together with certain relatively small deposits in the main basin, mostly near sewer outlets, as detailed in the engineer's report.

Besides these three conditions which the committee deems essential, it recommends the following. The separate system of drainage for the Stony Brook valley and some other portions of Boston, as recommended in the report of the street department, sewer division, for the year 1901, should be begun and extended with reasonable rapidity, and on the Cambridge side the separation already begun should be extended, beginning with the upper reaches of the basin.

Salt water should not be admitted into the basin under the fresh water, as was suggested at the hearing, nor in any other way, unless under some unusual condition.

The banks of the basin should be so sloped and finished as to leave no small pools or shallow spots for the breeding of malarial or other mosquitoes; and the many breeding-places of these pests now existing near this great water park should be destroyed.

It is important to preserve the greatest possible water

area; and, in building the embankment on the Boston side of the river, between the West Boston and Cottage Farm bridges, authorized under chapter 435 of the Acts of 1893, to be constructed 300 feet wide in the rear of Brimmer Street and 100 feet wide in the rear of Beacon Street, the surface of the river should not be encroached upon more than is necessary.

Your committee recommends Craigie bridge as the site of the dam for the following reasons: —

The borings indicate a good foundation there. This site continues the water park opposite the whole of the Charlesbank, and brings it nearer to the crowded portions of the North End of the city of Boston. The chief reason, however, for the location decided on, is that it will serve for a new bridge. The present Craigie bridge is old, and will soon have to be rebuilt. It serves as the only artery from East Cambridge and Somerville to Boston. It is near many of the large freight yards, is much crowded with heavy teaming, and many electric cars cross it. Blocks are frequent, and property would undoubtedly be improved in the neighborhood were a broader roadway supplied.

Character of the Structure recommended.

The committee refers to report of the chief engineer for a more detailed description of the structure which is recommended.

In brief, it is intended to serve both as a dam and as a bridge and to have substantially the construction recommended by the Joint Board of 1894.

That Board recommended a dam with a 100 foot roadway. We suggest that this width be increased by 30 feet in order to provide a space of from 15 to 25 feet in width along the up-stream edge, on which suitable seats can be placed, giving the inhabitants of the neighboring thickly-settled districts of Boston and Cambridge convenient opportunity to enjoy a view of the basin.

We also recommend a somewhat higher grade for the top of the dam near the lock and draw, similar to that proposed by the city engineer in bridge designs Nos. 3 and 4, and for the same purpose, namely: to admit tug-boats and barges without masts to pass the lock without interrupting the traffic over the bridge.

We recommend a lock 350 feet in length between gates of a clear width of 45 feet, with a drawbridge of 50 feet clear opening, with a depth over the sill of the lock of 13

Charles River at Lemon Brook. Tide at Grade 8.

Charles River at Lemon Brook. Low Tide.

feet at mean low water. It will be noted that these dimensions of the lock are considerably larger than those recommended by the petitioners or by the Joint Board of 1894. To increase them further would add an amount to the cost of construction and maintenance which appears out of proportion to the actual or prospective demands of navigation.

On examination of the various studies and plans proposed, including that of the Joint Board of 1894 on file in the office of the State Board of Health, your committee felt that it was not necessary to make fresh detailed drawings for construction, inasmuch as the drawings prepared for the Joint Board appear sufficient for the preliminary estimate.

Our engineer has reviewed these original drawings and estimates, and reports that he finds no recent developments which would lead to any material change except for the increased quantities, due to a somewhat larger cross-section of the stream at Craigie bridge and to increased width of the dam and its greater head room at the drawbridge.

Making ample allowance for these increased quantities, together with a margin for increased cost of building operations at the present time, we consider that these additional expenses will be covered by the addition of $590,000 to the estimate of the Joint Board, making the total cost of the dam, including roadway, drawbridge and lock, $1,250,000, or substantially the same as the cost of equivalent bridge No. 3 as estimated by the city engineer (exclusive of grade damages).

Cost.

The cost of a bridge will be about as much, or perhaps more, than the whole cost of the dam. The West Boston bridge is to cost $2,500,000, the Charles River bridge has cost $1,500,000. Four estimates have been made by the Boston city engineer for the cost of a new bridge to replace the Craigie bridge, the first being $864,430, the second $1,148,458, the third $1,463,362, and the fourth $2,044,687. The cost of the dam is stated by our engineer as follows: "The cost of the dam, including bridge and lock combined, would cost but little if any more than the equivalent bridge 100 feet in width."

As to the cost of the whole undertaking, the dam itself should not be charged to the basin improvement account, but should be charged to the same cities as would have to pay for a new bridge. The work required to be done in the Fenway should be charged wholly to the city of Boston; for that work, already recommended by Boston officials,

should be done, even if a dam is not built. The construction of the embankment and filling in the rear of Beacon and Brimmer streets, already authorized by statute to be paid for by the city of Boston, should also be paid for by that city, excepting whatever excess of cost may be necessitated by the construction of the marginal conduit recommended by your committee. The cost of maintenance will be but little more than the cost of maintaining a drawbridge, which would fall in any case on the cities maintaining a bridge. For this reason no separate estimate is included.

The total cost of the recommendations of your committee, properly chargeable to the account of the improvement of the basin by a dam, will be : —

Marginal conduit on Boston side from Leverett Street to Fens outlet,	$500,000
Extension Fens outlet to St. Mary's Street,	200,000
Marginal conduit on Cambridge side,	150,000
Dredging of basin recommended by engineer,	25,000
Dredging Broad and Lechmere canals and rebuilding walls,	40,000
Keeping channels in and to Broad and Lechmere canals open from ice, capitalized,	100,000
General contingencies,	221,000
Total,	$1,236,000

The above does not include the extension of the Stony Brook conduit through Fens to Charles River.

As against this expenditure the following saving will be effected over the plans of improvement of the basin now in progress.

Saving on sea wall between Cambridge Street and St. Mary's Street,	$173,000
Saving on sea wall on Cambridge side,	112,000
Saving on grading on Cambridge side,	100,000
Approximate saving on Metropolitan Park Commission work for construction remaining to be done, in case water in the basin is held at grade 8, will be,	425,000
Total,	$810,000

From which it appears that the plan here proposed will entail an expense of only $426,000 above that of the treatment of the basin without a dam, and this without including the large expense necessary for dredging in case the basin is adapted for public use without the aid of a dam.* When in

* It is estimated by Percy M. Blake that the dredging below the Cambridge, River Street, bridge to grade —5 would cost $479,168; while the dredging above this bridge to the same grade would cost $537,777; total $1,016,945.

The engineer's estimate of the dredging necessary in case a dam is built is $25,000, in addition to the cost of dredging materials for dam and embankment which is included in the estimate of the cost of the dam.

Hamburg. Alster Basin. Die Stadt von der Uhlenhorstgesehen.

View of Shore of Charles River Basin Back Street, in Rear of Beacon Street.

addition to this the gain in public health, in increased commerce and in public pleasure are considered, the immediate carrying out of the work recommended would seem to be a measure of wise public policy and of economy as well.

Apportionment.

Your committee proposes to distribute the cost of the improvement of the basin proper, seven-twelfths to the city of Boston, three-twelfths to the city of Cambridge and one-twelfth each to the city of Newton and the town of Watertown.

The distribution of expense just suggested would assign the following amounts to the different cities and town respectively: —

Boston,	$721,000
Cambridge,	309,000
Newton,	103,000
Watertown,	103,000

Commission of Construction and Maintenance.

Your committee recommends, as a commission to have charge of the construction and maintenance of the dam, the mayors of the cities of Cambridge and Boston, and the Metropolitan Water and Sewerage Board *ex officiis*. The latter is composed of three members, one of them being the chairman of the State Board of Health. That commission has recently constructed some very large dams, involving much greater engineering difficulties than the dam proposed. It also has charge of the metropolitan drainage systems, and is now building large sewers much more difficult of construction than the marginal conduit and the continuation of the Binney Street sewer. It has in its employ also experts on the question of purity of water and the disposition of drainage. It would seem that no Board is better equipped for constructing this dam and maintaining the basin in good condition than the Metropolitan Water and Sewerage Board, with the help of the mayors of the cities of Cambridge and Boston and the city engineers, who will act under the control of the mayors of those cities.

The committee further recommends that the following amendments to existing acts be adopted: —

Be it enacted, etc., as follows:

Section 1. Chapter three hundred and forty-four of the acts of the year eighteen hundred and ninety-one, as amended by section one of

chapter four hundred and thirty-five of the acts of eighteen hundred and ninety-three, is hereby further amended by inserting in said section one, after the words "thence running southerly by a straight line", the words "or a curved line"; and after the words, "to the point in Charles river", and before the words, "three hundred feet distant westerly", the words, "not less than one hundred feet nor more than"; and by inserting after the words "but no part of said wall shall be less than one hundred feet nor more than three hundred feet westerly from said commissioners' line"; and by omitting the word "straight", after the words "southerly and westerly from the aforesaid", and before the word "line"; so that said section one, as amended, shall read as follows: "*Section 1.* The city of Boston may, by its board of park commissioners, build a sea wall on the Boston side of the Charles river from the sea wall of its present park, situated between Craigie's bridge and West Boston bridge, to the sea wall of said river in the rear of Beacon street in said city, on or within the following lines: Beginning at a point in the south-west corner of the stone wall of the Charles river embankment, or Charlesbank, thence running southerly by a straight line, or a curved line, to a point in Charles river not less than one hundred feet nor more than three hundred feet distant westerly from the harbor commissioners' line, measuring on a line perpendicular to the said commissioners' line at its intersection with the southerly line of Mount Vernon street; but no part of said wall shall be less than one hundred feet nor more than three hundred feet westerly from said commissioners' line; thence continuing southerly and westerly from the aforesaid perpendicular line, on such lines, curved southerly and westerly from the aforesaid line, as said board of harbor and land commissioners shall approve, to a point one hundred feet or less distant from said sea wall in the rear of Beacon street; thence by a line parallel with said wall to the westerly line of the public park of said city, known as the Back Bay fens, extended to intersect said line parallel with said sea wall."

SECTION 2. Section three of said chapter four hundred and thirty-five of the acts of eighteen hundred and ninety-three is amended by omitting the words beginning, "The said city shall, in addition to the said dredging of material for filling", and ending with the words, "in their judgment is an equal improvement to the harbor of Boston"; and by inserting, after the words "and to the provisions of all general laws applicable thereto", the words, "but no compensation shall be required by said board from the city of Boston on account of said sea wall and filling"; so that said section three, as amended, shall read as follows: "*Section 3.* The material used for the filling authorized by said chapter shall, to such grade as shall be required by the board of harbor and land commissioners, be dredged from Charles River basin in such places and to such depths as the said board, having due regard to the requirements of navigation, the improvement of said basin and the quality of material suitable for such filling, shall from time to time prescribe. All of the filling, dredging and other work authorized or required by this act shall be subject to the direction and approval of said board and to the provisions of all general laws applicable thereto; but no compensation shall be required by said board of the city of Boston on account of said sea wall and filling. The filling, dredging and other work authorized by this act shall also be subject to the approval of the secretary of war and to all laws of the United States applicable thereto."

SECTION 3. This act shall take effect upon its passage.

Be it enacted, etc., as follows:

SECTION 1. That chapter five hundred and thirty-one of the acts of eighteen hundred and ninety-eight be so amended that the board of metropolitan park commissioners will have authority to build a bridge instead of a dam from Cambridge to Boston at the point therein prescribed for building a dam; and that the provisions of said chapter for the construction of said dam, as far as applicable, shall apply to the construction of said bridge.

SECTION 2. This act shall take effect upon its passage.

The committee submits the following draft of a bill: —

AN ACT TO AUTHORIZE THE CONSTRUCTION OF A DAM ACROSS THE CHARLES RIVER, BETWEEN THE CITIES OF BOSTON AND CAMBRIDGE.

Be it enacted, etc., as follows:

SECTION 1. The mayor for the time being of the city of Boston and the mayor for the time being of the city of Cambridge shall, with the metropolitan water and sewerage board, all acting *ex officiis*, constitute the Charles river basin commission.

SECTION 2. Said commission shall construct, maintain and operate a dam across Charles river, with a suitable lock, waste ways, etc., between Boston and Cambridge. Said dam shall be substantially at the present site of Craigie bridge. Said dam shall not be less than one hundred feet in width at the top, so built as to allow for a roadway of that width, with drawbridge over the entrance to the lock, and shall be of sufficient height to be capable of holding back all tides.

Said commission is authorized to apply for and take all necessary steps to obtain the approval of the secretary of war or other proper authorities of the United States for carrying out the purposes of this act.

Each member of said commission shall be paid his actual travelling expenses and all such other expenses as may be incurred by him in the performance of his duties under this act, as shall be allowed by the governor and council.

SECTION 3. As a condition precedent to the completion and operation of said dam, said commission shall carry out or cause to be carried out all the recommendations made by the committee on Charles river dam appointed under resolves of nineteen hundred and one, chapter one hundred and five, as amended by resolves of nineteen hundred and two, chapter one hundred and three, in its report of January fourteen, nineteen hundred and three, excepting as the same may be modified by said commission with the approval of the state board of health.

SECTION 4. The supreme judicial court or any justices thereof, and the superior court or any justices thereof, shall have jurisdiction in equity to enforce this act and any order made by said board in conformity therewith. Proceedings to enforce the same shall be instituted and prosecuted by the attorney-general, by the request of said board or any other party in interest.

SECTION 5. Said commission may allow damages to any wharf owners or others on account of the construction and maintenance of said dam, and said board may also dredge canals between Craigie bridge and West Boston bridge, and do such other dredging as they may deem proper in said basin; and may strengthen or rebuild wharves or other structures near said dredging; and they may provide for breaking

channels through the ice in winter above said dam within the basin; and they may assess betterments for said dredging and strengthening or rebuilding of wharves, under the general law authorizing the assessment of betterments, with like remedies to all parties interested.

SECTION 6. Any person entitled by law to any damage for taking of or injury to property under authority of this act may appeal from the decision of said commission, within thirty days of said decision, to the superior court for the counties of Suffolk or Middlesex, on petition therefor; said damages to be determined by a jury, under the same rules of law, as far as applicable, as damages are determined for taking of lands for highways, under the provisions of law authorizing the assessment of betterments.

SECTION 7. To meet the expenses incurred under the provisions of this act, except for the annual repair and maintenance, the treasurer and receiver-general shall, with the approval of the governor and council, issue notes, bonds or scrip, in the name and behalf of the Commonwealth and under its seal, for a time not less than ten nor more than forty years from their respective dates, which shall bear interest at a rate not to exceed four per cent. per annum, payable semi-annually, and to be designated "The Charles River Basin Loan," and be issued as the governor and council shall direct.

The treasurer and receiver-general shall establish a sinking fund and apportion an amount to be paid each year, sufficient, with its accumulations, to extinguish the debt at maturity.

SECTION 8. So much of the debt in the preceding section as shall be caused by the construction of the dam itself shall be apportioned by said board on the basis of its being a substitute for a bridge among such cities as shall be directly benefited by its use as a highway, after giving a hearing to said cities, in such proportion as may seem best.

The cost of any work done hereunder within the fenway and the cost of the park in the rear of Beacon and Brimmer streets, as authorized by the acts of eighteen hundred and ninety-one, chapter three hundred and forty-four, as amended by the acts of eighteen hundred and ninety-three, chapter four hundred and thirty-five, shall be charged to the city of Boston. The annual payments for interest and sinking fund on so much of the debt as is provided for under this section shall be paid by the respective cities in proportion to their share of this portion of the debt charged to them hereunder.

SECTION 9. The annual payments for interest and sinking fund on so much of the debt as is not already provided for in the preceding section, together with the annual cost of maintaining, operating and repairing said dam and basin, and of other work done under authority of this act, and such dredging below the dam, if any may be required from time to time by the secretary of war, on account of the existence of said dam, shall be paid, seven-twelfths by the city of Boston, three-twelfths by the city of Cambridge, one-twelfth by the city of Newton and one-twelfth by the town of Watertown.

SECTION 10. The Boston park commission, duly authorized to construct said park in the rear of Beacon and Brimmer streets, shall construct said park in a manner to allow the commission herein established to build in the best and most economical manner the marginal sewer, as recommended by said committee on the Charles river dam, which shall be completed before the operation of said dam.

SECTION 11. The roadway on said dam within its limits, as determined by said commission, shall be surfaced or paved, policed and maintained by the cities of Cambridge and Boston; and all damages

recovered in any action of law by reason of any defect or want of repair in any such roadway shall be paid by such cities equally.

SECTION 12. The Boston and Maine railroad shall remove its freight bridge next below said Craigie bridge, and shall rebuild the same further down, so as to allow a distance of at least four hundred feet in the clear between said bridge and the lower face of said dam, and shall remove the piles of said old bridge, all at the expense of said railroad company.

SECTION 13. No action shall be taken relative to dredging or to strengthening or rebuilding of wharves under this act, until the plans therefor have been duly submitted to the board of harbor and land commissioners, and received their approval thereon.

SECTION 14. This act shall take effect upon its passage.

HENRY S. PRITCHETT.
SAMUEL M. MANSFIELD.
RICHARD H. DANA.

BOSTON, MASS., Jan. 14, 1903.

REPORT OF JOHN R. FREEMAN, CHIEF ENGINEER.

HENRY S. PRITCHETT, LL.D., *Chairman, Committee on Charles River Dam.*

DEAR SIR: — The chief questions demanding consideration by your engineer, after the proposition and the evidence had been reviewed, appeared to be the following: —

I. In general, the benefits and disadvantages resulting from proposed dam.
II. Best type of dam, complete or half tide.
III. Best location.
 (*a*) Just above Broad canal.
 (*b*) Just above Lechmere canal.
 (*c*) At Craigie bridge.
IV. Most advantageous elevation of water surface; grade 8, Boston base, or higher. Effect on ground-water levels of neighboring territory.
V. Fresh water basin *v*. salt water; comparative advantages.
VI. Necessity for large tidal sluices.
VII. Present condition of Fens basin: analogy to proposed basin.
VIII. Quantity of upland water flowing into the proposed basin.
IX. Purity of this upland water.
X. Extent of the present pollution of Charles River basin; means of lessening this.
XI. Amount of pollution admissible without offence.
XII. Remedies for the unavoidable pollution.
XIII. Means for circulating water in Fens basin and Cambridge canals.
XIV. Lessening pollution of basin by extending separate system of sewerage.
XV. Effect of stagnation of water in proposed Charles River basin upon odor, appearance and character of water.
XVI. Effect of this stagnant fresh water basin on health; malaria.
XVII. Effect of lessening the tidal prism upon the shoaling of Boston harbor.
XVIII. Effect of dam upon navigation and commerce in Charles River basin, in Cambridge canals and in upper harbor.
XIX. Storm flood levels in proposed basin; frequency or probability of ever flooding the marshes after dam is built.
XX. Cost of dam and lock, with and without special tidal sluices.
XXI. Cost of marginal conduits for increasing cleanliness of waters of basin.
XXII. Cost of making good any injury to navigation resulting from dam.
XXIII. Cost of dredging foul sludge banks.
XXIV. Cost of shore line improvements.

The foregoing questions will be found discussed briefly under the corresponding numerals beginning at p. 64.

In order to secure data for the proper discussion of the above topics, I was led step by step into many extended investigations, and compelled to seek assistance from several specialists.

I have had these investigations reported in the form of a series of appendices, and have given the methods, the facts and their interpretation, all with much detail, because of this subject having been so many years before the public, and *in order that others may have full and convenient opportunity to judge of the adequacy of the new data secured and of the reasonableness of our conclusions.*

In accordance with your request I have carefully examined the evidence presented at the public hearings, and have given particular attention to the reports of studies by experts presented on behalf of the opponents. I have also carefully reviewed the evidence presented at the hearings before the Harbor and Land Commission in 1894 and the original report upon the improvement of Charles River by the Joint Board of 1894; also the series of ten reports made between 1861 and 1866 by the Board of Commissioners on Boston Harbor, and all reports made in connection with the public works of the metropolitan district suggested as bearing on the problems under discussion. In brief, I have sought earnestly to comply with your desire that these matters be reviewed so thoroughly and impartially that, whatever the conclusion, the question could be regarded as settled for a generation.

The Massachusetts Board of Harbor Commissioners in their review of the evidence of 1894 had urged strongly that certain matters be further investigated and more facts determined before final opinions were formed.

It became plain, early in these studies, while reviewing the evidence presented at the hearings of 1902, that a principal cause for sundry important differences in the opinions expressed regarding the desirability of the proposed dam lay in the inadequacy of the data of clearly proven facts, and the consequent recourse to assumptions made from different points of view. Therefore, with your approval, I made sundry investigations, which may be briefly outlined as follows : —

New Researches, and Data derived from them.

(*A*) *Surveys and Soundings of Basin.* — A new large-scale, contour map of the basin was prepared from new surveys and soundings, because it was found that the existing maps had been rendered worthless over a large portion of

this area by the great changes in the bed of the basin made by dredging material to form the embankments for the Cambridge parks, for the speedway and for filling of large areas of private lands.

The wash of material stirred up by these operations, together with deposits from sewage and street wash, had also doubtless contributed to some shoaling in other parts of the territory in question.

This new map was desired as an aid in studying the requirements for navigation, for the purpose of estimating the cost of improving the muddy shores and marshes of the upper basin, and the cost of dredging several large, objectionable mud flats exposed at low tide, and for its aid in studying the biological conditions of the basin in case the dam was built and the water held nearly stagnant at constant level, because depth and light has a very material influence upon the growth of algæ and micro-organisms; and salt water in deep pockets becomes very foul and is displaced by fresh water very slowly.

(B) Influence of Present Tidal Basin on Temperature of Air. — A careful study was made of the influence of the present tidal basin upon the temperature of the surrounding air, both immediately over the water and for some distance back from the Boston and Cambridge shores. Ten self-recording thermometers were stationed at various representative localities, and ten other mercurial thermometers were stationed at other representative localities all the way from Boston Light to Norumbega Park, and read several times daily for a little more than two months. Great care was taken in the calibration of these thermometers, and also in locating them so as to obtain proper exposure.

The result of all these thermometric readings was to show that *the basin now cools the temperature of the air on the shores around the basin and at the street level over the middle of the basin by hardly more than a single degree Fahrenheit from 10 A.M. to 4 P.M. on the hottest days;* and it is proved by these very numerous and careful observations, beyond the shadow of a doubt, that the apparent coolness of the air on hot summer days near the present basin is almost wholly due to the wind, in very much the same way that the face is cooled by the motion of air from a fan.

Water Temperatures. — The temperature of the water was also observed several times daily, beginning the last of June and ending the middle of September, at Boston Light,

Deer Island Light and at the drawbridges and at sundry other stations along the Charles River as far as Riverside.

From all these observations, it appears that *the average July and August temperature of the proposed fresh-water basin would not be warmer than the present tidal basin by more than three degrees Fahrenheit.*

Taking, for the mid-day temperature, the average from 10 A.M. to 4 P.M. *of the twelve hottest, sunniest days* between July 28 and Sept. 12, 1902, we found the

Sea water temperature at Boston Light,	62° F.
Harbor water temperature by mean of six stations,	65° F.
Estuary water temperature by mean of three stations,	70° F.
Upland water temperature by mean of four stations between Watertown dam and Riverside,	74° F.
Air temperature, Boston, mean of Weather Bureau, Institute of Technology, Harvard Observatory,	77° F.

From these observations the remarkable fact appears that *the salt water of the present tidal Charles basin in the warmest weather is only four degrees cooler at mid-day than the fresh Charles River water between Watertown, Waltham and Newton.*

Similarly, taking the mid-day temperature for *every* day throughout the summer, the difference would manifestly be less; and because the wide basin is deeper than the up-stream waters, and better exposed to wind and evaporation, the temperature of its water will probably be somewhat cooler than that in the shallow mill ponds up stream, and no reason appears why, with the pollution restricted by the means proposed, the warmth of the future basin should encourage a much more luxuriant growth of algæ here than the same (or a slightly higher) temperature does in the same water a few miles up stream.

(*C*) *Study of Fens Basin.* — The Fens basin, which certain persons have suggested was, in its present foul and offensive condition, a fair example of what the Charles River basin would become if the dam were built, has been studied from the stand-points of its history, its hydraulics, chemistry, biology, pathology, and, we venture to add, common-sense. These matters will be found set forth at considerable length in Appendix No. 3.

Its hydraulics are found very different from what was testified to at the hearings. The circulation of water found during the three weeks of our test was only about one-fourth part as great as had been supposed. The rise and fall at each tide was only about 9 inches, instead of 18 inches, and

its regulating gates were found leaking so badly that 60 per cent. of the water admitted at high tide leaked back on the ebb without circulating through the basin. The present actual circulation brings in less new water each day than required for diluting the volume of foul flow that constantly enters it in dry weather.

The new Stony Brook channel has been allowed to become a channel for dilute sewage, and chemical analyses have shown a highly putrescent quality in the refuse which enters it from various sources.

The chemist finds the Fens water badly polluted by sewage, insufficiently diluted and mostly devoid of oxygen, and finds an offensive amount of putrefaction going on in the sludge deposits over its bottom.

The biologist finds the lower layers of water mainly devoid of aerobic organic life, its oxygen used up, and little opportunity for fresh aeration, because of the difference of specific gravity between the upper and the lower strata of water.

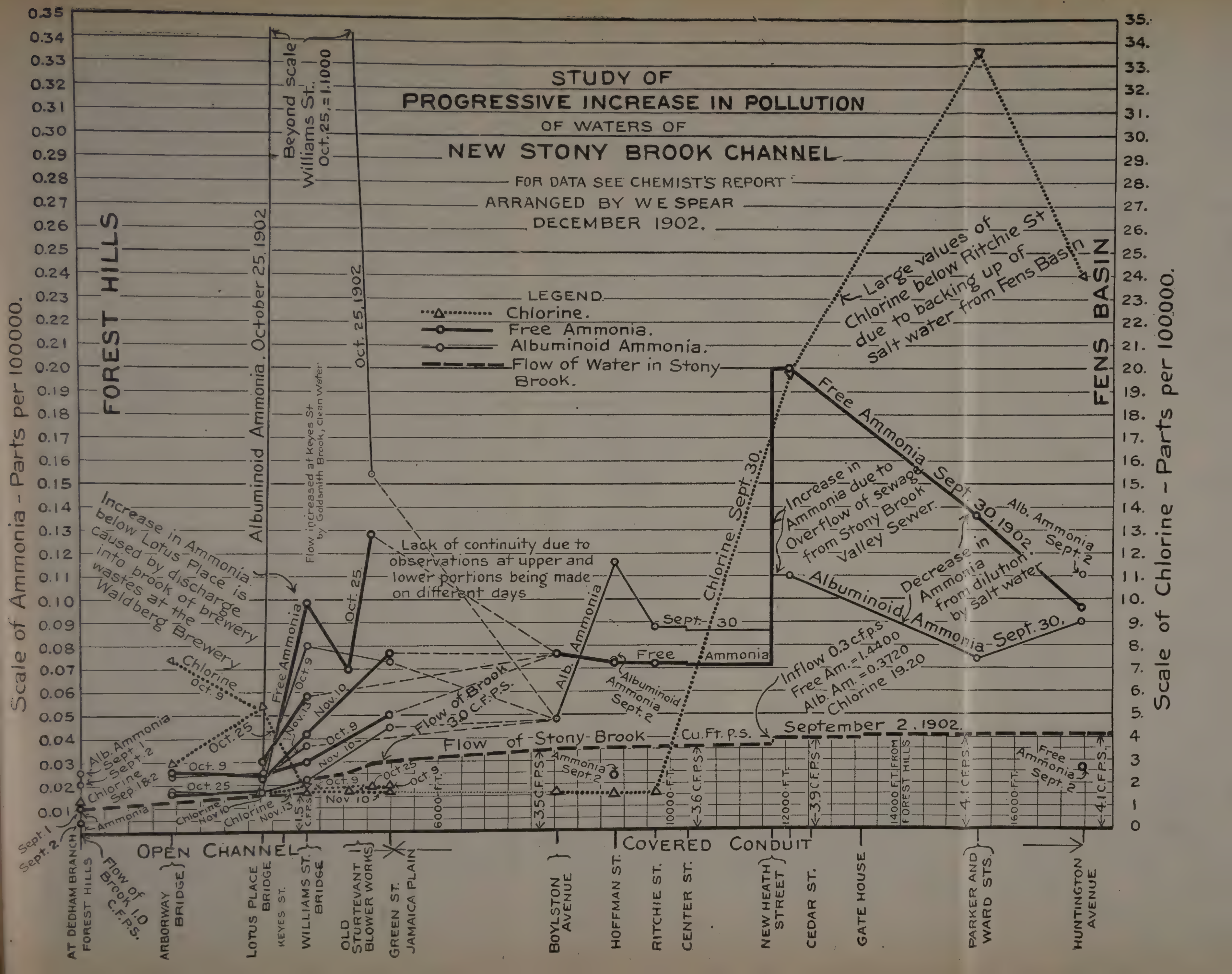
And, as a matter of common-sense, the continued admission of sewage into Stony Brook, transforming it, in a run of two miles, from the bright, clear country stream found just above Forest Hills, to a condition which one skilled observer has described as resembling "a long septic tank," and then passing it into a park and diluting it less than half as much as is easily possible with the means at hand, passes understanding. The present condition of this basin could be greatly improved at small expense.

We made soundings and borings over the entire area of the Fens pond to determine the depth and volume of the water and the depth and volume of the sludge requiring excavation. We find that it contains upwards of 50,000 cubic yards of foul sludge, and that there is one-third as much sludge as there is of water in this pond.

Historically, I find that the present continuously offensive condition began only in 1897, and followed immediately upon the turning of the dry-weather flow of the sewage-polluted Stony Brook into the Fens, this foul flow having been previously excluded; and about the same time a change was made in the method of renewing the water.

The comparison of the probable future condition of the fresh-water Charles basin to the present condition of the Fens basin is, in my opinion, based on a very superficial examination, and is unjust.

(*D*) *Pollution. Chemical Analysis of Water.* — A study of the present pollution in the Charles River basin, the Fens



STUDY OF
PROGRESSIVE INCREASE IN POLLUTION
OF WATERS OF
NEW STONY BROOK CHANNEL
FOR DATA SEE CHEMIST'S REPORT
ARRANGED BY W E SPEAR
DECEMBER 1902.
LEGEND.
Chlorine.
Free Ammonia.
Albuminoid Ammonia.
Flow of Water in Stony Brook.
Scale of Ammonia - Parts per 100000.
Scale of Chlorine - Parts per 100000.
FOREST HILLS
FENS BASIN
Beyond scale Williams St. Oct. 25.=1.1000
Albuminoid Ammonia, October 25, 1902
Oct. 25, 1902
Flow increased at Keyes St by Goldsmith Brook, clean water
Increase in Ammonia below Lotus Place is caused by discharge into brook of brewery wastes at the Waldberg Brewery
Lack of continuity due to observations at upper and lower portions being made on different days
Large values of Chlorine below Ritchie St due to backing up of salt water from Fens Basin
Increase in Ammonia due to Overflow of sewage from Stony Brook Valley Sewer.
Decrease in Ammonia from dilution by salt water
Free Ammonia Sept. 30, 1902.
Albuminoid Ammonia Sept. 30.
Chlorine Sept. 30.
Alb. Ammonia Sept. 2
Inflow 0.3 c.f.p.s. Free Am.=1.4400 Alb. Am.=0.3720 Chlorine 19.20
September 2. 1902.
Flow of Stony Brook Cu. Ft. P.S.
Flow of Brook 3.0 C.F.P.S.
OPEN CHANNEL
COVERED CONDUIT
AT DEDHAM BRANCH FOREST HILLS
Flow of Brook 1.0 C.F.P.S.
ARBORWAY BRIDGE
LOTUS PLACE BRIDGE
KEYES ST.
WILLIAMS ST. BRIDGE
OLD STURTEVANT BLOWER WORKS
GREEN ST. JAMAICA PLAIN
BOYLSTON AVENUE
HOFFMAN ST.
RITCHIE ST.
CENTER ST.
NEW HEATH STREET
CEDAR ST.
GATE HOUSE
PARKER AND WARD STS.
HUNTINGTON AVENUE
14000 FT. FROM FOREST HILLS

basin, and in the Charles River above the Watertown dam was undertaken by means of chemical analyses, over six hundred and fifty samples of water having been collected and analyzed during the latter part of the summer and the early fall. I called to our assistance, for this study, one who has had a practical experience in the chemistry of water pollution probably not exceeded by any one in this country, — the chemist of the Massachusetts State Board of Health. His report will be found in Appendix No. 4.

We have reason to be very grateful for the cordial response of the State Board of Health to my request for the aid of its corps of chemists in this work, and for the energetic work performed. There is probably not another laboratory in this country where we could have obtained so much assistance and such valuable assistance in so short a time.

After I had observed the circumstances under which sewage sludge is deposited where the polluted fresh Stony Brook enters the salt basin of the Fens, I questioned whether the presence of salt in the water was not a disadvantage, by interfering with beneficent decomposition of impurities through organic life; and whether fresh water, with abundant life, might not receive a given amount of pollution with less chance of offence to sight and smell than salt water, and gave the more attention to this because of the presence of salt having been mentioned by many with approval, as if it were an aid to keeping the basins sweet and wholesome.

Therefore, sundry experiments were undertaken at the Lawrence Experiment Station of the Massachusetts State Board of Health, designed to increase our knowledge as to the comparative effect of dilution of sewage by salt water, brackish water and fresh water.

The results are very instructive, and show a decided superiority in fresh water, and a decidedly greater tendency to precipitate a sludge and give off offensive odors in salt water.

Certain other experiments were designed to show the difference in bacterial purification between water slowly moving and water at rest, which, taken with wide experience upon polluted water entering ponds and flowing streams, shows that stagnation in the proposed basin is not a condition that need be feared. "It is not running water, but quiet water, which soonest purifies itself," or most readily has its pollution disposed of by the activities of organic life.

Special studies have also been made with samples of the

silt and mud from various parts of the basin of Charles River, with a view to learning its probable influence upon the purity of the water held above it. Bacterial counts have been made, under Mr. Clark's supervision, on a great many of these samples of water.

The chemist's conclusions will be found stated in great detail in the appendix devoted to his report. We may summarize the most important of those relating directly to the proposed basin as follows: —

(*a*) Although there are local pollutions, as a whole, the water of the present Charles basin gets well mixed in going through the bridge piles (soon to be removed), and is found to be fairly clean, with an abundance of free oxygen. The water of the Fens is overburdened with sewage, and its lower strata contain no free oxygen.

(*b*) Although the upland water, as it enters the basin in time of ordinary low summer flow, is somewhat discolored by dyes and factory washings, it always (except perhaps very rarely in extreme drought) contains an abundance of free oxygen, and it does not contain more organic matter than can be taken care of and rendered innocuous by the proportion of free oxygen contained, and such water if held stagnant in a pond would probably continually improve. This conclusion was reached after many experiments on incubation of this water, etc.

(*c*) The old and the new Stony Brook conduits continually discharge dilute sewage; Muddy River outlet is at times polluted; there are several places where the water is polluted by factory waste; and in time of storm considerable amounts of sewage overflow, also much street wash, enter the basin. But if all the pollution now entering were discharged into the nearly stagnant, fresh-water lake produced by the proposed dam, it is doubtful if this pollution would rob its water of all its dissolved oxygen and thereby lead to the generation of the offensive gases of putrefaction. It would probably be absorbed.

This conclusion was reached after an extended series of experiments by incubation of Charles River water containing various percentages of sewage. The chemist confirms this conclusion from a study of the analyses of the polluted Abbajona River water and the bettered condition of this water after storage in Mystic Lake, which was, until re-

cently, used as a portion of Boston's water supply, and which has recently become a favorite resort for pleasure boating.

The turbidity and pollution from street wash and sewer overflow are now for a time mainly held as a thin layer at the surface, because of this fresh water being so much lighter than the salt, thereby exaggerating the appearance of pollution. With a fresh-water basin the same pollution would be at once more evenly diffused through the depths, and give less apparent defilement to the surface.

In case the proposed dam is to be built, in order to give the surface of the water a more attractive appearance, and as a safeguard against offence arising from the fact that the entrance of sewer overflows is intermittent, not uniform, the following improvements are recommended by the chemist: —

(*d*) The pollution now entering from the Beacon Street houses should be diverted into a sewer.

At least a portion of the pollution that now enters the basin through the Stony Brook channels should be excluded, particularly the highly putrescent brewery waste.

The outlets of polluting material from the abattoir and the starch factory near it should be more efficiently guarded.

It is possible, but not certain, that the dredging of a few of the present sludge banks in the Charles will be required.

(*e*) Better conditions would prevail for absorbing sewage pollution with the basin filled with still fresh water than if filled with still salt or brackish water. By an extensive series of experiments it is proved that salt water tends to a much greater precipitation of the impurities of sewage in the form of putrefying sludge than fresh water; and numerous other tests show that, when a given percentage of sewage is added to salt and fresh water under similar conditions, offensive odors arise much sooner from the salt water than from the fresh.

The salt water of the harbor, to begin with, averages containing less dissolved oxygen than the upland water which enters this basin, and this dissolved oxygen is found used up in the salt water to a greater extent in a given time than in the fresh.

This oxygenation is produced through bacterial agencies, and the quicker absorption of the free oxygen in the salt water, also the relatively greater number of anaerobic (or putrefactive) bacteria found able to live and work under salt-water conditions, leads naturally to the larger production of offensive odors.

In the fresh-water experiments, both with and without the bottom of the tank covered by polluted mud from the bed of the Charles, there were relatively more bacteria, but they were mainly aerobic, or bacteria effecting decomposition rather than putrefaction.

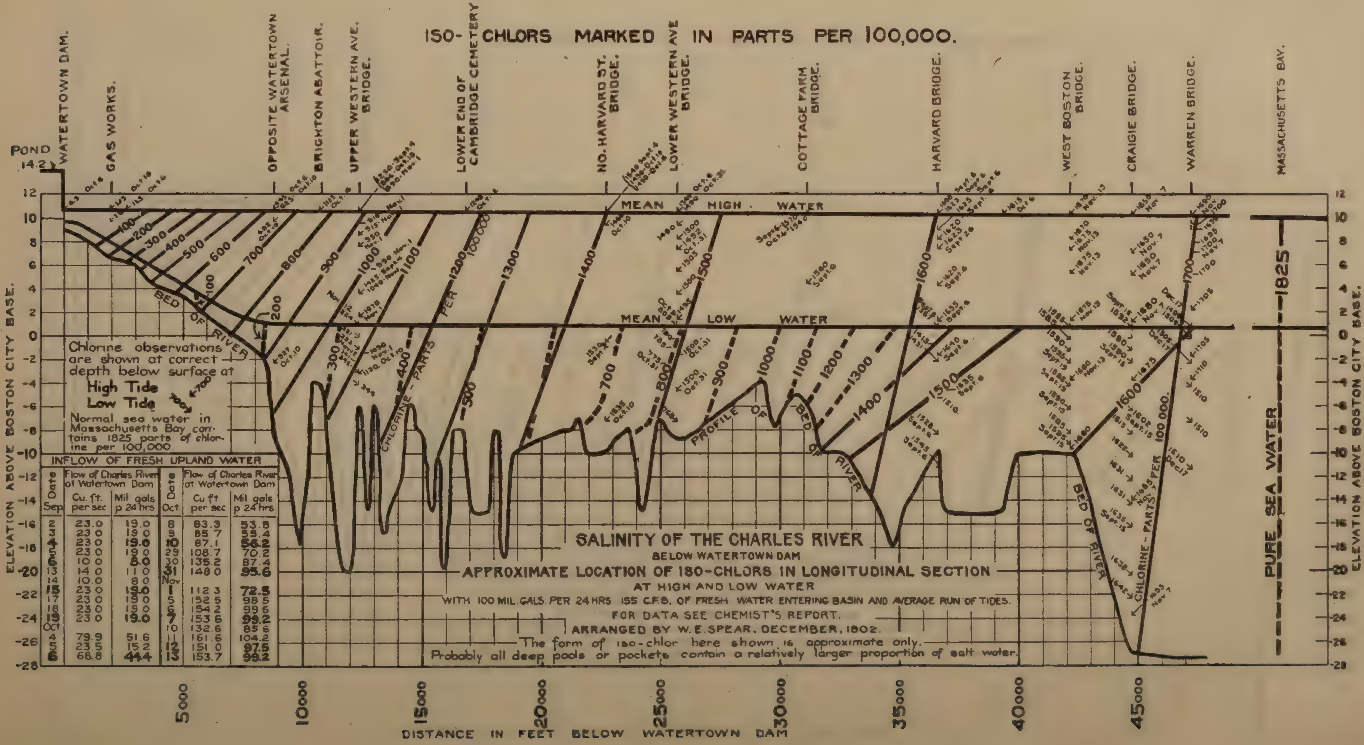
(*f*) The popular belief that running water purifies itself more readily than still water is fallacious. It is found to be the fact that with oxygen present, and equally good conditions for proper bacterial growth, the still water purification is fully as energetic.

(*g*) It does not appear probable that growths of algæ will cause trouble.

From the data given by Mr. Clark's report we have constructed the diagram inserted opposite this page, to exhibit the progressive decrease of the salinity of the present basin as we proceed up stream toward the Watertown dam.

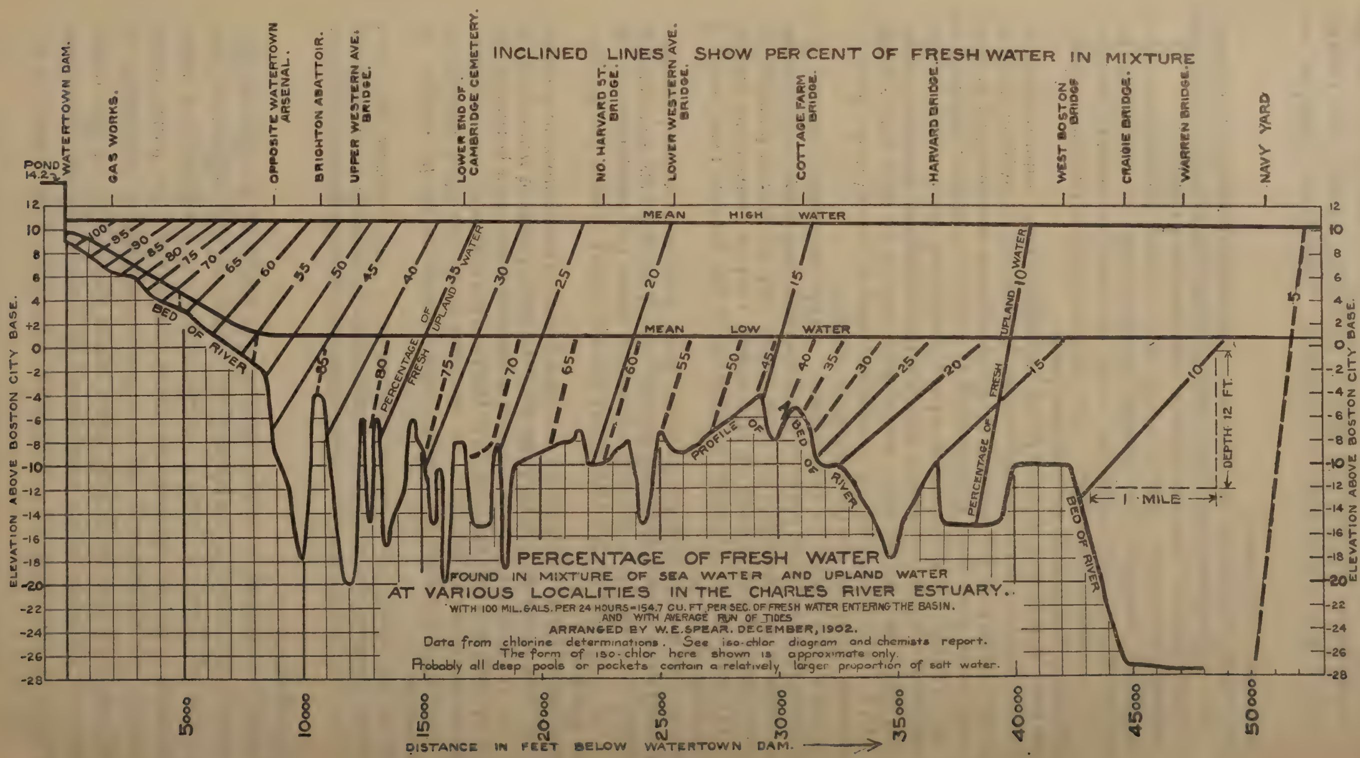
(*E*) *Pollution. Bacterial Analyses of Water.* — Bacterial analyses, designed to exhibit the comparative degree of pollution in different parts of the Charles River basin, the Fens basin and in the water flowing in from above the Watertown dam, have also been made, under the direction of Dr. Theobald Smith. These observations were extended so as to lead to a clearer understanding of the degree of flushing received by the present Charles River basin under the ebb and flow of the tide; and they indicate, more fully than the chemical analyses, that the returning tide brings water that, while not very foul, is far from pure.

(*F*) *Malarial Conditions.* — The report of investigations relative to malaria, made at your request, form a separate Appendix, No. 1. The pathologist who made these studies has long been celebrated as a most skilful observer in this line of work. His researches for the United States government on the cause of the Texas fever are well known, and his recent call to direct the work of the newly established laboratory in New York for research on contagious disease is a testimonial to the esteem in which his work is



INFLOW OF FRESH UPLAND WATER

Date Sep	Flow of Charles River at Watertown Dam: Cu. ft. per sec	Flow of Charles River at Watertown Dam: Mil gals p 24 hrs	Date Oct	Flow of Charles River at Watertown Dam: Cu ft per sec	Flow of Charles River at Watertown Dam: Mil gals p 24 hrs
2	23.0	19.0	8	83.3	53.8
3	23.0	19.0	9	85.7	55.4
4	23.0	19.0	10	87.1	56.2
5	23.0	19.0	29	108.7	70.2
6	10.0	8.0	30	135.2	87.4
13	14.0	11.0	31	148.0	95.6
14	10.0	8.0	Nov		
15	23.0	19.0	1	112.3	72.5
17	23.0	19.0	5	152.5	98.5
18	23.0	19.0	6	154.2	99.6
19	23.0	19.0	7	153.6	99.2
Oct			10	132.6	85.6
4	79.9	51.6	11	161.6	104.2
5	23.5	15.2	12	151.0	97.5
6	68.8	44.4	13	153.7	99.2



PERCENTAGE OF FRESH WATER
FOUND IN MIXTURE OF SEA WATER AND UPLAND WATER
AT VARIOUS LOCALITIES IN THE CHARLES RIVER ESTUARY.
WITH 100 MIL. GALS. PER 24 HOURS = 154.7 CU. FT. PER SEC. OF FRESH WATER ENTERING THE BASIN.
AND WITH AVERAGE RUN OF TIDES
ARRANGED BY W. E. SPEAR. DECEMBER, 1902.
Data from chlorine determinations. See iso-chlor diagram and chemists report.
The form of iso-chlor here shown is approximate only.
Probably all deep pools or pockets contain a relatively larger proportion of salt water.

held. I am told by competent authority that there is no man in America more competent to pass on these questions of effect of the proposed basin upon the health of the community by promoting or retarding conditions favorable to malaria. It is, therefore, most reassuring to learn that, following years of study on the origin of malaria, and after having repeatedly explored all parts of the adjacent territory, devoting a large part of his summer to this study, he reports: —

(*a*) "It is quite firmly established that the micro-organism of malaria which produces the well-known disturbances in the body by multiplying in the red blood corpuscles is transferred . . . by a certain species of mosquito."

(*b*) "The malarial microbe is a true parasite in all its stages. *It never exists free in the air or in the water or on vegetation*, but spends its life partly in the blood of man, partly in the organs of the mosquito."

(*c*) "All shallow pools in which water may stand for a portion of the year, and which are cut off from the permanent bodies of water so small fish cannot enter, may become breeding-places of mosquitoes, and should be filled up."

(*d*) "As regards the river itself, we may safely assume that the proposed basin will not become a breeding place for mosquitoes," if so treated as to contain abundant fish life, and if its banks are so treated as not to afford protection for mosquito larvæ from their natural enemies, the small fishes.

(*e*) Impurity or pollution of water, as in the present Fens basin, if made fresh water instead of salt, would tend to restrict the natural enemies of the mosquito, the little fishes, and, by greatly favoring the growth of fresh-water algæ, might eventually lead to the multiplication of *culex* and *anopheles* mosquitoes. "This necessarily implies the removal of all sewage from the Fens basin."

(*f*) "*In reviewing all the conditions likely to prevail in the future in and about the Charles River basin, there seem to be none which would tend to the increase of malaria* provided the suggestions made are carried out. In fact, the improvement of the banks and the territory beyond them *would be a great improvement on present conditions*, and tend to relieve those near the marshes of all mosquitoes now breeding in these places, *and perhaps remove the causes of malaria prevailing at the present time*, unless such malaria is due to bodies of fresh water beyond the immediate confines of the proposed basin."

(*g*) "Fresh water *v.* salt. The substitution of a fresh-water basin for the present tidal reservoir would not tend to intensify malarial influences, providing the present breeding-places of mosquitoes are properly dealt with. There would be a material improvement over present conditions, both as regards mosquitoes and malaria."

(*h*) "The introduction of salt water from the harbor will probably not be needed, and should be reserved as an artificial remedy for extreme unforeseen conditions."

(*G*) *The Unavoidable Pollution. Biological Studies.* — I soon came to believe that a hopeful remedy or means for taking care of such pollution of the water as may be

unavoidable is its absorption by the activities of organic life.

I found it necessary to call in expert biological assistance for studying the conditions affecting microscopic and other life within the Fens basin and the Charles, both in its tidal estuary and above the Watertown dam, with a view to obtaining a clearer idea of what was necessary in order to establish biological equilibrium within the proposed basin; and for such light as a brief examination could shed upon the degree of pollution which could be admitted and absorbed by organic growth without causing offence; and for learning more about the probable result of changing from salt water to fresh water, and the results of an occasional flushing of the basin with salt water. This biological study was extended to cover an inquiry into the relative adequacy of salt water, fresh water and brackish water for supporting life, and for transforming and rendering harmless the impurities received.

The man called upon for this work had, after graduating at Brown some fifteen years ago, studied at Johns Hopkins, then at the celebrated biological laboratory at Naples, Italy, had continued these studies while an officer of instruction in biology in Brown University, and later as professor of biology at the Rhode Island Agricultural Experiment Station. While at the latter station he had given much attention to studying offensive conditions that had developed in the brackish Point Judith Pond, in which circulation of sea water had been cut off by natural causes. His report is given in Appendix No. 6, and brings out many interesting facts.

One important point brought out in this biological study of the Fens basin was *the influence on organic life of the prevention of aeration in the lower strata of water, where the specific gravity at the top of the water differs greatly from that below, thereby restraining vertical circulation.*

I have felt that the ideal toward which we should work in planning this large basin was that of a "balanced aquarium," and I greatly regret the lack of time for carrying these studies beyond the point merely sufficient for making sure that the proposed construction is safe, and that a fresh-water basin is best.

The investigations of the biologist show in brief, for *the special conditions of this problem:* —

(*a*) "The Fens basin . . . affords no fair or proper standard by which to judge the proposed Charles Basin."

(*b*) "Fresh water . . . will be better adapted for receiving sewage without causing offensive deposits or offensive odors than either salt or brackish water."

(*c*) "It appears probable that the organic life in the proposed fresh-water basin can assimilate the greatest amount of pollution that the engineers estimate it is likely to receive, without causing offence."

(*d*) "The occasional introduction of salt water into the basin should be avoided."

(*H*) *Pollution by Overflow of Sewage.* — The problem of the overflow of sewage mingled with storm water from sewers in Cambridge, Boston and the up-river towns, following heavy rains, has been studied with great care, and maps of these sewer systems have been compiled. Nearly every one of the fifty or more regulator gates controlling sewer overflows has been gone into and inspected. For several months I sought all opportunities for personally inspecting the overflows of sewage into the basin at low tide in time of storm. The new Stony Brook conduit, which receives the discharge of many sewer overflows, has been inspected repeatedly throughout its length, and the old conduit examined for a few hundred feet, or sufficiently to reveal its foulness.

This problem of estimating the quantity of sewage that may escape into the Charles River because of sewer overflows is one of extreme difficulty, — far more so than was anticipated; one reason is, that the sewer system of old Boston and Roxbury is extremely complicated, and contains many ancient sewers that were extended as the "made land" encroached upon the tidal flats and marshes, some of which are so outgrown and overloaded that in some of the small, old districts the extra flow of "washing day" is said to be almost sufficient to cause overflow.

All these matters will be found reviewed in much detail in Appendix No. 2.

We have reviewed and analyzed the Binney Street "sewer clock gauge" records in great detail, in order to learn their exact bearing upon the general problems of the amount of sewage overflow. We have also reviewed and analyzed all of the records of all the other sewer clocks, at the Bath Street, Lowell Street and Massachusetts Avenue district outlets, and also the records of the clock gauge in the Charles River valley sewer, and we have set several additional sewer clocks on outlets along the Boston sewer system, for comparison with the Binney Street records and the rainfall records.

We have also studied every one of the 77 sewer overflow districts individually, and compiled tables of population, impervious surface, etc., and have made estimates of the amount of sewage that each will probably contribute to the Charles after the new high-level sewer is finished and connected.

Speaking in general terms, I find: —

From the large and representative Binney Street district less than 3 per cent. of the total annual output of sewage enters the Charles, instead of the 7 per cent. assumed by several experts as the basis for their opinions; and during the six summer months, from May 1 to November 1, in which time alone could the overflow of sewage give noteworthy offence, *I believe it certain that not more than about 3 per cent. of all the sewage produced in all the territory tributary to the Charles in Boston and its suburbs will find its way into the Charles* after the new high-level sewer is put into use; and it appears certain that for twenty years to come, or as far as can be foreseen, this quantity will decrease. The tributary population, now about 300,000, will be decreased to not above 250,000 by diversion of flow from territory now tributary, on completion of the new high-level sewer two years hence; and the separation of sewage and storm drainage in future will without doubt progress fast enough to offset growth in population.

I believe that the amount of sewage entering the basin in the summer months would not exceed the amount that would be constantly discharged by a population of 7,500, perhaps not more than from 5,000, and I feel certain it could not possibly exceed that from a population of 10,000.

Experience on the discharge of sewage into other Massachusetts waters makes it appear entirely safe to say that a flow of less than 8 cubic feet per second of such water as now comes down over Watertown dam into this proposed "stagnant" reservoir will be ample to dilute and absorb the ordinary pollution from 1,000 persons without offence, if this pollution is well diffused through the water; and measurements of the river flow at Waltham make it certain that the summer flow, or for these six months, in all ordinary years, is more than sufficient for this degree of dilution of all the pollution that would enter if no marginal conduits are built.

Nevertheless, the intermittent character of the pollution and the storm flushing of concentrated filthy deposits and the added pollution due to street wash, with a population more dense in the future, have led me to propose marginal

conduits, and these conduits are recommended also because of their utility in promoting circulation in the Fens and in the canals.

It further appears that the basin will be thoroughly flushed out by the flood waters every spring, and that the 458,000,000 cubic feet of clean, fresh water that it will contain *could take care of the summer flow of sewage for three months with no inflow of fresh water whatever.*

This appears an ample factor of safety for extreme drought and for the almost complete holding of the river flow by the mills at Waltham, which has certainly occurred in times past for weeks at a time, and concerning which volume of river flow I have also made an extended investigation.

(*I*) *New Studies of Amount of Dilution required to make Sewage Inoffensive.* — Apparently the sanitary experts who made statements at the hearings regarding this had based their evidence concerning the permissible degree of pollution mainly upon certain statements and investigations that were first presented in the Report of the Massachusetts State Board of Health, 1890, special water supply volume, pp. 785–793. Those investigations are now twelve years old and did not rest on so many examples as are now available, and moreover contained a warning against discharge of sewage into ponds.

During the past ten years much additional knowledge of these matters has been obtained by the few skilled observers in this line, although very little that is new has been published.

Fortunately for present purposes, the Legislature of a year ago had directed the State Board of Health to investigate the discharge of sewage into rivers through the State, and a large quantity of new data had thus been obtained under the supervision of the chairman of its water supply committee, Mr. Hiram F. Mills, and its chief engineer, Mr. X. H. Goodnough. It is certainly beyond doubt or question that no set of men in the United States have had so broad an opportunity to study these matters intelligently during the past ten years as those connected with the Massachusetts State Board of Health. Therefore, it is with great pleasure that I report the yielding of Mr. Goodnough to my earnest request, and his laying aside of other work to collate the results of these observations in form for our use.

He finds that *many streams and ponds of the State receive, without offence or serious objection, a much larger quantity of pollution than that which can by any reasonable possi-*

bility enter the proposed basin, and in general the results of this broader experience fully confirm the conclusions set forth in the special water supply volume of the State Board of Health for 1890, p. 791, but define the limits with more precision, and add a new line of data on the pollution of ponds.

(*J*) *Flow of Water from the Upland Charles.* — We made continuous gaugings of the quantity of water entering the basin from the Charles River above Watertown dam, by means of a weir and a recording gauge, for two months, until stopped by ice and by pressure of other work. We made these gaugings because it was found that the use of the water by the factories at Waltham and elsewhere materially interferes with its uniform delivery, and that in severe drought the flow is sometimes nearly all held back by these mill dams for several weeks at a time. These investigations show that the supposed analogy to the observed flow of the Sudbury River, on which certain of the evidence presented at the hearings was based, fails badly at times.

I personally examined the water power records of the Boston Manufacturing Company for the past twenty years, and found many instances of holding back the flow, and Mr. George T. Jones, mechanical superintendent of these mills for the past twenty years, tells me that they have on several occasions held back so nearly the entire flow that the Waltham Bleachery, located next down stream, and which we find uses only about 10 cubic feet of water per second, has had to ask them to open the gates and let enough water flow to supply them. Finding that a thorough study would require more time than I could devote to this, Mr. Richard A. Hale, principal assistant engineer of the Water Power Company at Lawrence, who has had thirty years' experience in accurate water measurements, was engaged to study into this with all possible thoroughness. Mr. Hale's report and the results of our own gaugings are given in Appendix No. 16.

Our two months of daily gauging unfortunately did not include a period of extreme drought, and, although our observations were continuous night and day for two months, this period was too brief to serve for much more than the confirmation of other data. Our apparatus for this measurement has been turned over to the State Board of Health, that they may continue the gaugings for some years to come, as a part of their regular studies of discharge of the important rivers of the State.

(*K*) *The Flood Discharge of the Charles.* — Since certain statements made at the hearings of 1892 were calculated to cast doubt on the sufficiency of the estimate of flood discharge adopted by the Joint Board in 1894, Mr. Hale was also asked to continue the review that I had begun of the records of flood discharge at the mills in Waltham, which extend back many years, and to compute the quantity of flood discharge and confirm it by all records that could be obtained at the other factories, from Watertown to Newton Upper Falls; and to also study the conditions affecting flood delivery, — for these matters have a most important bearing upon the height to which water may rise in the proposed basin above the dam in extreme floods at time of high tide.

The investigation proves beyond a doubt that the Charles River is a very uncommon river, for this part of the country, in the slowness and moderation of its rise and the long duration of its run-off. This makes it much easier to take care of floods in the proposed basin, and the unquestioned fact that Stony Brook now has a quick water-shed, while the flood on the Charles responds very slowly to the rainfall, makes it certain that, under those conditions which produce extreme floods, the water from Stony Brook would have been nearly all delivered before the main flood from the upper Charles began to arrive, and shows that the extreme of a Stony Brook freshet will not be superimposed upon the top of a Charles River freshet, as was assumed, without justification, by some of those who testified on this subject at the hearings. I am satisfied that in the greatest flood of the past twenty-five years, "the Stony Brook flood," so called, the actual flood volume of the Charles was safely inside the estimates presented by Messrs. Stearns and Goodnough.

(*L*) *Dredging in Boston Harbor.* — In order that it might plainly appear to what extent the present navigation channels are artificial, I had Mr. J. R. Burke, assistant engineer, Massachusetts Harbor and Land Commission, compile a map showing all dredging up to date, from the records of the office with which he is connected, and also from the United States Engineer Office at Boston. This map will be found opposite p. 386, and shows that the important channels of the upper harbor are nearly all the production of the dredge, and it is also found in this connection that in all of this dredging, so far as can now be learned, the digging (except that near wharves and old sewer outlets) has been mainly in the original clay, which is found but thinly covered by mud or silt. *None of the dredging has been for digging out material that had silted up or shoaled an original main*

channel, except, perhaps, some of that in the extreme upper harbor near the mouth of the Mystic River. *The channels of Boston harbor, once dredged, are found to retain their depth remarkably well.*

(*M*) *Measurement of Velocity of Harbor Currents.* — A new study of the currents in Boston harbor has been undertaken, and some hundreds of measurements made of the velocity of the water in various representative localities and throughout all stages of the tide, *close to the bottom*, for it is this bottom velocity that determines the question of scour or shoaling. A new determination of the distribution of velocity in vertical and horizontal planes at the three principal controlling sections for tidal currents has been made, at various stages of the tide, with the aid of special current meters kindly loaned to us, one by the United States Coast Survey, two others by direction of the Chief of Engineers. So far as could be learned, no investigations of this special subject had ever been previously made with such a degree of completeness or accuracy as would be considered necessary according to the standards of to-day.

As a result of our measurements, we find the bottom velocity is much smaller than the velocity given by floats near the surface, and inadequate in force to produce scour in the kind of material of which the bed of the harbor is chiefly composed. These measurements are described in detail in Appendix No. 11. One interesting feature of these current measurements was the discovery that much of the time pulsations were going on, which in their slow regular period could be likened to the long ground swell commonly found near the harbor entrance. The rise and fall of the rapidity of the click of the electric sounders which recorded the revolutions of the meter were nearly always apparent to the ear, and while we did not have the opportunity to study this subject fully, it appears that the velocity of the current on the swell of these pulsations may be increased fully 10 per cent., and the power of the current to scour thereby materially increased.

(*N*) *Geology of Boston Harbor.* — I felt that no study of the effect of a change in the tidal prism upon the preservation of the harbor would be adequate without fuller knowledge of the conditions which produced this depression or indentation of the coast line. Therefore, I requested the gentleman who, so far as I can learn, has studied the geology of the Boston basin in every part most profoundly for the past

twenty-five years, who is now consulting geologist on the East Boston tunnel, and whose previous writings on the general geology of this region are a standard authority, to make this question of the origin and preservation of the harbor a special study, from the stand-point of the geologist. He was also asked to give particular attention to the character of the sub-strata in the immediate vicinity of the proposed dam site.

He has made an examination of all available records of the borings in different parts of the harbor and the adjacent estuaries; has personally examined the material now being dredged at Bird Island flats, etc.; and we have sought to compile a complete record of all known bed-rock borings, for foundations, elevator plungers, etc.

The geologist's report is given in Appendix No. 7, and will be found exceedingly interesting. His maps of contours of the bed rock and of the hardpan or bowlder clay cannot fail to prove of great value in many other engineering studies in and around Boston.

His conclusion is, that the surging back and forth of the tidal prism has probably done more to shoal the harbor as a whole than it has to deepen it, and that the *harbor is essentially a drowned valley*, a valley excavated by the meander of the larger streams flowing while the ice cap was melting at the close of the glacial epoch, probably ten thousand years ago and the valley afterwards submerged by the slow subsidence of this whole region, at the rate of perhaps only 5 or 10 feet in a thousand years, to the extent of from 30 to 50 feet, and of which actual subsidence there are many proofs. The reasonings and the conclusions are set forth in much detail in Appendix No. 7.

(*O*) *Borings in Silt Deposits in Harbor.* — We cut out 34 sample cores, from 2 to 4 feet in depth, or well down into the blue clay, of the material now forming the bed of the harbor at various representative localities, mainly in areas where a comparison of ancient soundings with modern soundings had indicated that shoaling had occurred. It has long been questioned by some of those familiar with hydrographic work whether the small differences in depth found in the main thoroughfares between the surveys of 1835–65 and 1888 were due to scour and shoaling, or due in part at least to errors of measurement; for all of these soundings were made rapidly for general purposes, obviously with no attempt at precision, probably with a light lead and a hemp line, from a moving boat, from an oscillating surface and

partly in currents rapid enough to sway and belly out the hemp line in the 20 to 40 foot depth to a varying degree, according to the height and set of the tide.

It appears absolutely certain that wherever the hard blue clay free of shells is found, this represents the original floor of the harbor, and that this was deposited where it now lies thousands of years ago. Therefore, if we cut down into the blue clay and measure the thickness of the overlying silt and find this thickness smaller than the alleged shoaling, it is obvious that one at least of the two sets of old soundings compared must be in error.

For obtaining these samples I adopted the simple expedient of an 8-foot piece of 2-inch wrought iron pipe with a thin sharp end, on the outside of which was mounted a 30-pound ring of lead freely sliding up and down, and striking against a collar on the pipe, which weight, worked by a rope from the surface, was used like the ram of a pile-driver to hammer the pipe down into the harbor bottom. The apparatus was easily handled from an anchored scow and could be used in any depth of water. The pipe was provided with a valve at the top. A leather cup loosely fitting in the bottom of the pipe protected the top of the core, and the plug of hard blue clay secured the bottom of the core. A hard pull on tackle and davit drew the pipe out of the harbor bottom and brought it to the surface and on board the scow, when a piston was introduced at the top end of the pipe and the core pushed out on to a board for examination. Freezing weather stopped us in this work, but the cores obtained were from several different representative localities, and prove that the deposit of silt is thin, and tend to disprove the supposed shoaling shown by the soundings; for these sample cores generally show that the depth of soft material now found on top of the hard, original blue clay floor of the harbor is less than the supposed shoaling found by a comparison of ancient and modern soundings.

The decrease in tidal area caused by cutting off the Charles basin will be only 60 per cent. as great as the tidal areas previously cut off from the harbor by filling the flats; and, if shoaling naturally follows a reduction of tidal flow, it would have shown itself more conspicuously in these sample cores (see map opposite p. 379).

(*P*) We have given much attention to the navigation interests, and it has been sought to so plan the improvement that a great benefit to the manufacturing interests and the navigation interests should be obtained. These studies re-

ceived a new impetus from the statements presented by Mr. Albert E. Pillsbury at the hearing of Oct. 10, 1902, on behalf of the owners of wharf properties along the Charles.

After reviewing his statements and revisiting the properties of his clients I came to feel that these requirements, if interpreted literally, might be construed to call for a much larger expenditure than Mr. Pillsbury and his clients had supposed. Moreover it appeared to me that they had underestimated or not allowed sufficiently for the manifest betterments due to ability to reach their wharves at any hour and to shift position at any hour, or the gain from no longer straining the hulls by allowing heavily loaded vessels to lie aground while the tide was out. Plainly this was a case demanding expert assistance, and I sought the advice of the man who has for more than twenty years been the engineer actually in charge of the investigations and constructions of the Massachusetts Board of Harbor and Land Commissioners, and was more familiar than anyone else of whom I could learn with the practical conditions of stability of dock walls in Boston harbor and the reasonable requirements of navigation in this particular region.

While it had appeared clear to me, from inspecting the walls all around the margins of the basin and from talking with disinterested parties, familiar with past and present conditions, that the shipping interest of the Charles basin is on the decline, and of comparatively small importance at present, and that part of the large tonnage shown during the past year or two has come from handling the large quantities of piles, lumber and granite required in the building of the Cambridge bridge, it nevertheless appears true that the keeping of the facilities for navigation opened and unimpaired may serve a very useful purpose, and be of great financial benefit to the citizens of Cambridge, Brookline, Newton and Brighton, by keeping water competition alive as a means of regulating railroad freights on coal and building materials.

Around the twenty miles of shore line that the Charles River basin and its canals present there is ample space for a great future development of manufacturing, without encroaching to any objectionable degree upon the utilization of the natural beauties of a large part of the shore line for park purposes; and with this prospective factory development there will come an increased commerce by water.

I would vigorously oppose the suggestion that factories are not wanted around this basin, by pointing out the plants of the Cambridge electric station and the University Press

as examples of industrial architecture that need give no offence, and by the further suggestion that the natural location for factories is in situations like those along the Broad canal and the Lechmere canal, and that many other sites between Craigie bridge and the Watertown dam exist, eminently suitable for industrial development.

One chief requirement for a factory location is an abundance of fresh water for steam purposes and purposes of condensation. This matter was well set forth by the distinguished mechanical engineer, Mr. E. D. Leavitt, Jr., of Cambridge, in a letter presented with the evidence of 1894.

The water of the Charles would be entirely suitable for these purposes, thereby conserving the far more expensive supply brought in by the metropolitan water works.

We cannot now see far enough into the future to say what its industrial developments may be; but it is plain that it would be wrong to in any way impair the opportunities for this by limiting the benefits of free navigation, particularly since these can be secured with very small additional expense.

For example, the site of the lock is already deeper than necessary; therefore, it will add comparatively little to its cost if a depth over the sill sufficient for all ordinary coastwise traffic is provided. Second, the filling of the proposed esplanade will absorb the results of a large amount of dredging.

The present channel is very crooked and obscure. If the proposed new channels are built as near to the foot of the embankment walls as the economy and security of wall foundation will permit, this channel, although its edge be 40 feet away from the wall, will serve a very useful purpose in aiding in the preservation of the purity of the water in the basin, by bringing the main current, due to upland water, particularly in those seasons of the year when the flow of the Charles River is greatest, and the periods of sewage overflow most frequent and of longest duration, up close to the point where these overflows discharge.

It is a fact of hydraulics that the strongest current tends to follow the line of greatest depth; and by dredging the material for the embankments from channels near the margins, the strongest current will be brought close to the point where any pollution must enter the basin. In other words: Pollution will be most efficiently absorbed, if divided among many outlets, and it is simpler and better to bring the main current up near to the outlets of sewer overflow than to extend these many overflow channels beneath the basin out to the present main channel. With the adop-

tion of marginal conduits, the overflows of storm water mingled with sewage from these conduits into the Charles will be so rare and so dilute that there is much less reason for inducing a current near the shore than if the marginal conduits were not to be built.

(*Q*) An investigation of the pollution of the waters of the Broad canal and the Lechmere canal was made, and conditions found which it was believed would make their appearance offensive after the basin was held at a constant level unless means for flushing or circulating the water could be found.

Although this matter was not touched upon in the evidence presented in 1894 or 1902, an inspection of these canals and their surroundings at low water shows that they now receive much pollution from oil, gas, tar waste, privy drainage, factory waste and stable drainage; and although much of this could be forced into the neighboring sewers, the waste that will naturally come to these canals from the shipping and from the factories along their shores appears to demand some further provision.

At each of a half-dozen inspections that I have made of Broad canal at low tide, I have noticed more of the iridescence and evidence of oil, tar and gas manufacturing waste in the outlet of Broad canal than at any other point on the Charles.

Fortunately it is found that very simple means can be provided, which appear certain to accomplish all necessary circulation and keep these canals at all times filled by an inward current of clean, fresh water from the basin, which shall be suitable for steam purposes, and of great service and economy to the factories already in this district and to the future factories which are likely to be built there, with the improved conditions for navigation.

The simple method proposed consists in utilizing a portion of the present Binney Street overflow conduit, which now stands idle 95 per cent. of the time, and which was originally built for a trunk sewer, but which, since the construction of the North Metropolitan Sewer system, has been used only for a storm overflow channel, and which runs conveniently near to the head of these two canals.

The connection at the head of each canal would consist merely of a cast-iron pipe, perhaps 48 inches in diameter, provided with a suitable adjustable weir and gate at its up-stream end, and a simple tide gate at its down-stream end, where entering the 9-foot Binney Street conduit.

I propose that a marginal conduit leading from the Binney Street sewer overflow channel be extended for a distance of about 2,000 feet beneath the parkway known as "The Front" down to a point just below the proposed dam site at Craigie bridge, crossing under the outlet of the Lechmere canal by means of a siphon, terminating just below the bridge in a sort of masonry catch-basin, having double tide gates at its outlet.

The present outlet from Binney Street into the basin would be reconstructed with an appropriate overflow weir, so as to retain the full advantages of the basin's water level at grade 8 or 9, for relieving the Cambridge storm drainage from the flooding of streets and cellars that now frequently occurs in storms at high tide.

One great advantage of this marginal conduit combined with the inflow weirs from the canals is that it serves the double purpose: first, of keeping out of the basin the pollution of this largest and perhaps dirtiest of the Cambridge sewer districts, with its street washings, sewer flushings and floating fæces; second, it affords a continual inflow and flushing of these two canals with clean water, with almost no expense for attendance and maintenance, and no expense whatever for pumping; and at the same time it will preserve all the advantages of relieving the Cambridge sewers in great storm flows occurring at high tide.

(*R*) An investigation of various methods for inducing circulation in the future Fens basin has been studied. The committee received a formal protest from the faculty of the Tufts College medical school, located a few hundred feet distant from the foulest spot in the Fens basin, to the effect that they feared the basin would become exceedingly foul if the circulation now produced by tidal action in the Charles were discontinued (evidence, p. 83). Mr. Blake had anticipated similar objections by providing for circulating the water by a pumping engine of the propeller type, which he estimated would cost $50,000,* and could be maintained for the yearly sum of $6,000. After considering the desirability of the south marginal conduit for sundry other purposes, it appeared that it could be made to co-operate in securing circulation in the Fens after much the same manner that I have proposed on the preceding page for the Lechmere canal, without any expense whatever for steam or electric power and at no expense for constant attendance of fireman and engine man.

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* Evidence, Blake, p. 207.

For this purpose an intake near the Stony Brook bridge or near the Brookline Avenue gate house would be provided, consisting of a broad circular weir that could be closed when desired by a cylindrical gate, which, when open, would rise clear. This intake would communicate by a pipe, say 36 or 48 inches diameter, leading to the short new channel, by which the "foul flow" of the new Stony Brook channel is to be led into the old 7-foot conduit and thence into the proposed marginal channel. Automatic arrangements, similar to the sewer regulators, would be provided, by which the intake could be closed when rains or melting snows swell the flow of Stony Brook; or a similar arrangement can be attached to the Muddy River conduit near the Brookline Avenue gate house, if the marginal conduit is extended to St. Mary's Street.

This arrangement will permit of a broad open entrance from the Charles basin, by which canoes and boats can freely enter the Fens.

(*S*) At our request, the city engineer of Cambridge very kindly undertook new studies of their sewer system, with a view to developing an outline of a plan and determining the cost of the gradual abolition of storm overflows of sewage into the upper part of the proposed basin by carrying out the separation of sewage and storm water at a somewhat greater rate of progress than heretofore contemplated. Cambridge has already made much progress in this work of separation.

These studies are reported briefly in Appendix No. 14, and showed that the probable cost of constructing new sewers and drains for separating the sewage from the storm water in all that portion of Cambridge tributary to the Charles, and thereby excluding all of this pollution from the proposed basin, would be $767,783. The cost of changing over the house plumbing and drains for the 11,232 buildings within this area would probably add $100 per house, or $1,123,200, — a total of $1,890,983.

The Binney Street district alone would account for about $780,000 of the above, and the proposed Cambridge marginal conduit will answer all requirements for this Binney Street district, at a cost of only about $88,000. This leaves as the expense for separation of storm water and sewage in the remaining portion of Cambridge tributary to the dam about $1,111,000; but this work is not a "condition precedent" to the building of the dam.

(*T*) Studies have also been made in the Boston city engineer's office of a scheme for the progressive lessen-

ing of the discharge of sewage overflow in time of storm from the Boston main drainage system into the Charles basin, by separating the storm water and street drainage from the sewage, as had been already suggested in outline in the report of the sewer department for 1901, but beginning this work first on those districts where it would accomplish most in lessening the overflow of sewage into the Charles River. This work was placed in the hands of Mr. Louis F. Cutter, C.E., and is reported in detail in Appendix No. 15.

These investigations showed that the complete separation of sewage from storm water in those parts of Boston tributary to the Charles would cost about $4,705,000, while for the region west of the Fens, for which the reconstructed old Stony Brook channel would not serve as a surface water drain, the cost would be about $2,701,000.

Finally, it appeared that *both on the Boston side and on the Cambridge side the marginal conduit method of lessening the pollution was much quicker and more economical than the forcing of an early separation of all sewage from storm water*, and the conduits also serve for producing circulation in the Fens and in the Cambridge canals.

(*U*) We tried to repeat the ground-water level measurements of 1894 by utilizing the same pipe wells. We found only a few of them available, and a few ground-water levels were observed at such of the test wells mentioned in the report of the Joint Board as could be found. Further studies were planned, particularly in certain low districts near the Cambridge shore, and others above Exeter Street, and a well-boring apparatus suitable for this work was very kindly loaned us by the engineer of the Metropolitan Water and Sewerage Board, but the time proved insufficient, and it appears so plain to me from general principles that the proposed dam at grade 8 would not affect the present ground-water level injudiciously, and Mr. Stearns's reasons given on pages 26 and 27 of report of 1894 and in his evidence before the Harbor Commission are so clear and convincing on this point, that I was the more ready to defer this field work.

(*V*) The probability of the occurrence of a "Stony Brook flood" in conjunction with a "Minot's Ledge tide" was investigated, for in effect this had apparently been assumed in certain of the evidence presented as a means of showing

that the storage space in the proposed basin, after drawing it down on the preceding tide, would not suffice to contain the largest flood and the worst conditions for which there were precedents.

From the United States Coast and Geodetic Survey and from the Weather Bureau I obtained all available records of exceptionally high tides and exceptionally heavy rainfalls. These records are not complete, and serve to show that the extreme tides commonly come from strong, long easterly storms, and that these are commonly accompanied by considerable quantities of rain; but no case has yet appeared where the very extreme conditions of tide and storm flood have come together; and from the theory of probabilities it is plain that the chances of a rainfall like that of February, 1886, being superimposed on a tide like that of April 15–17, 1851, are very remote, and, if it did come, need not be feared.

Conclusions.

As a result of the studies of the evidence presented at the hearings of 1902 and 1894, and from the new data described above, and for other reasons which will be stated in detail in the following pages, I have reached the following conclusions: —

I. *The Balance between Advantage and Disadvantage is unmistakably in Favor of Building the Dam.*

It surely does not threaten the preservation of the harbor. It surely does not threaten the public health, and, if certain present intolerable defects in the sewer system are remedied, there is no danger that the water in the proposed basin need ever become offensive, or its condition be like the present condition of the Fens basin.

Taking the whole year through, the navigation of the Charles basin and the Cambridge canals will surely be improved by the dam. There will be some increased trouble from ice and some moderate expenditure for dredging and for strengthening certain walls.

After including liberal allowance for the cost of marginal conduits to intercept street wash and intercept sewer overflows, and to provide circulation in the Cambridge canals and in the Fens (precautions not contemplated in the report of the Joint Board of 1894, and which I regard more in the light of insurance, or factor of safety, and as *a contribution to the luxury of cleanliness* rather than a distinct necessity) this whole great public improvement is wonderfully cheap.

Advantages v. *Disadvantages.* — The principal advantages are: —

1. The magnificent opportunity at comparatively small expense for replacing unsightly tidal mud flats and unclean muddy shores now having indifferent surroundings by a great water park, somewhat similar, in its lower, broader portions, to the Alster basin at Hamburg, Germany, and possessing, in its upper, narrower portion, the advantages for wholesome recreation now found on the Charles River near Riverside; all near to the great centres of population and convenient of access to people of moderate means and limited leisure, requiring neither long walks nor long rides on street cars before it can be enjoyed.

Cambridge Shore above Western Avenue, Low Tide – Banks not improved.

Hamburg. Alster Basin. Fährhaus, Uhlenhorst.

2. A probable large increase in valuation of the marginal lands, now in private ownership, up stream from Harvard bridge, consequent upon the basin being made more attractive.

3. The lessened expense for development of the 16½ miles in length of park lands upon the margin of the Charles River already acquired by the Metropolitan Park Commission and the municipalities bordering the river, or otherwise dedicated to public or semi-public use, because of lessening the amount of filling and diking of the marshes and guzzles; the lessening of the amount of dredging or cleaning, and gravelling of muddy slopes within the tidal range on some long reaches up stream from Soldiers' Field; and on other long reaches bringing the possibility of clean, walled shores within reasonable cost.

4. The holding of the basin at a constant level between grade 8 and 9 instead of the present frequent rise to grade 11, and *restricting the highest necessary storm level to grade 11 at high tide, in the greatest storm of half a century*, instead of the occasional tides of 14 feet, and with an extreme record of 15.67 feet above Boston base, *would give improved sanitary conditions* throughout portions of the Back Bay district of Boston and throughout portions of Cambridge by lowering the extreme flood level in the present sewer and storm-water drains, and thereby give almost *absolute relief from liability to such overflows of sewage into cellars and over certain low territory as are reported to now not infrequently occur* during extremely heavy rainfalls at high tide.*

5. This constant water level at grade 8 or 9 will prevent the uncovering of large areas of foul-smelling and unsightly mud flats near Harvard bridge and other large areas of mud flats immediately below the dam at Watertown, and will prevent the uncovering of muddy or slimy banks and guzzles along the narrow portion of the river for nearly the entire distance up stream from Captain's Island to the centre of Watertown.

These areas lying above grade 0, Boston base, or uncovered at extreme low tide, are colored brown on the accompanying large contour maps of the present basin and the maps of the Cambridge canals.

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* On page 19 of report on prevention of floods in valley of Stony Brook it is stated that during a period of eighteen years there were 41 tides which rose above 13.14, city base; 19 tides which rose above 13.50, city base; 8 tides which rose above 14.00, city base; 3 tides which rose above 14.50, city base; 1 tide which rose above 15.60, city base.

The portion of the river above Watertown Arsenal is not ordinarily uncovered down to the mean low-water grade of 0.64, Boston base, because the water of this long channel has not time to drain out completely between tides, and because throughout most of the year the flow of upland water is sufficient to cover the bed of the stream, but in extreme drought in hot weather these up-river flats may become very offensive to sight and smell.

6. A lessening of the probability of malaria and a lessening of the mosquito pest will naturally follow the construction of the proposed dam, because of the obliteration of their breeding places after the better drainage of the marshes that will be rendered feasible through the construction of the dam.

The *anopheles* mosquito, which recent research has proved to be the chief and probably the sole agent in the dissemination of malaria, now breeds in stagnant pools along the upper portion of the proposed basin, and the *culex*, or non-malarial mosquito, breeds in the small pools in the present poorly drained marshes.

If a dam is built as proposed, it will be a simple, inexpensive matter to so change the contour, elevation and drainage of the sloping banks that almost every one of these pools of fresh or brackish water, in which mosquito larvæ now find safe shelter from their natural enemies, will no longer exist.

7. The full dam, as proposed, will prevent the flooding of a broad extent of marsh land in Brighton, Watertown and Newton, under the highest tides of every month, as now, for the high water at ordinary spring tides of each month averages 11.64. The average elevation of these marshes is about 10.7.

8. The constant water level at grade 8.0, Boston base, or perhaps 0.5 or 0.75 foot higher, will give improved conditions for navigation by coal-laden or other shipping, after merely dredging out from appropriate places the amount of material required for filling the marginal embankment authorized by the Acts of 1893. Mean high water in the lower portion of the Charles basin is probably very slightly lower than at the Navy Yard because of the resistance of the pile bridges. In the upper portion of the Charles basin the tide rises slightly higher than at the Navy Yard, by reason of the momentum of the current and the narrowing channel. These differences anywhere between Essex Street and Craigie bridge are hardly more than an inch, and for the basin as a whole the height at the Navy Yard may be used with sufficient accuracy for present purposes.

Lechmere Canal, below Sawyer's Lumber Wharf, Nov. 14, 1902.

Broad Canal, West of Third Street, July 11, 1902. Low Tide at Grade 0, Boston Base.

Mean high water, according to determinations of about twenty-five to thirty-three years ago, is now commonly reckoned at $0.64 + 9.8 = 10.44$, Boston base.

If the basin level is grade 8.5, about 2 feet of the depth for floating barges or schooners to their berths *during the hour of extreme high water, under mean rise of tide*, would be lost; while, if found feasible to maintain basin at grade 8.75 or 9.0, the loss of depth over the shoals would be correspondingly less. But, on the other hand, the tide does not reach so great a height as 10.4, Boston base, on about half of the days of the year, and the alternate tides of each day materially differ in height. The tide curves for four representative months — May and June, when the carrying of building material is probably most active, and September and October, when the coal trade may be assumed to be the heaviest — are given below; and by comparing this diagram with the maps of the two Cambridge canals, it will be seen how very short the available time now is in which a coal schooner of average depth can be berthed, and how great the saving in demurrage would be if the dam is built and a moderate amount of dredging done.

That the consideration of mean high tide as the present working level for navigation tends to obscure the facts and tends to exaggerate the real injury will be seen by reference to these diagrams of tidal range; for, *during the low neap tide periods, the tide does not now rise above grade 8, by the mean low water datum, for about a week at a time.*

By the United States Coast Survey tables of predicted tides at the Navy Yard, Boston, it will be seen that, in May, 1902, the tide did not rise above grade 8, mean low water datum (corresponding to 8.6, Boston base), in the hours of daylight, during the entire week between May 22 and May 29, and again during the neap-tide period, for about a week from June 17 to June 24, 1902, the day tide did not rise above grade 8, mean low water. The same is true for the week from Sept. 9 to Sept. 16, 1902; and also for five or six days from Oct. 8 to 13, 1902. And, in my opinion, *the gain from constant level at grade 8.0 or 8.5, in freedom to move in and out at all hours and in avoiding the severe strains that a heavily laden boat now receives while lying on the mud while the tide is out*, as shown in the photograph opposite this page, *fairly offsets the loss*. Nevertheless, as material will have to be dredged for filling the dam and the embankments, I would recommend that the additional expense be incurred by taking a part of this filling material from the Cambridge canals and from the channels in the main basin.

9. The constant level at grade 8.0 or 8.5 will permit a form of dock wall construction that will be more economical for the improvement of shipping facilities than can be obtained under the present mean daily tidal range of about 10 feet rise and fall, and the spring tide range of 12 to 13 feet rise and fall.

For a section of this wall, see p. 419 of Appendix No. 12.

Because of the constant level, only about 9 feet in vertical height of stone wall is required along these canals, or just height enough to expose a fire-proof and imperishable face to the weather, whereas, under present conditions, the custom has been to build these canal walls about 14 feet high.

10. There will be some gain in economy of power because of the cheap and generous supply of fresh water for steam and condensation made available to the electric stations and other steam plants, present and prospective, at sundry sites within a thousand feet of this sixteen miles of shore line of the Charles River, including the Broad and Lechmere canals, convenient for cheap coal. This feature was presented forcibly at the hearings of 1894, p. 653, by the distinguished mechanical engineer, Mr. E. D. Leavitt.

11. It can be easily proved, as shown by Mr. Blake's evidence, 1902, and by Mr. Stearns's estimate in the report of the Joint Board of 1894, that the cost of the dam, together with the cost of the auxiliary structures rendered necessary by the dam, will be far less than the expense of removal of the present exposed mud flats by dredging, the filling of the guzzles and other depressions of the surface, and the extra cost of protecting the shores by embankment walls, bulkheads, riprap, gravel beaches or other treatment under the present monthly range of 12 to 13 feet in the tide. The predicted normal tide rises frequently to grade 11, city datum, and in easterly storms frequently comes up to grade 13, and has once been up to grade 15.6, city datum. Notes on a number of extreme tides will be found in Appendix No. 18.

The height of the principal sea walls on Charles River in Boston is 15.0, and in Cambridge 15.5.*

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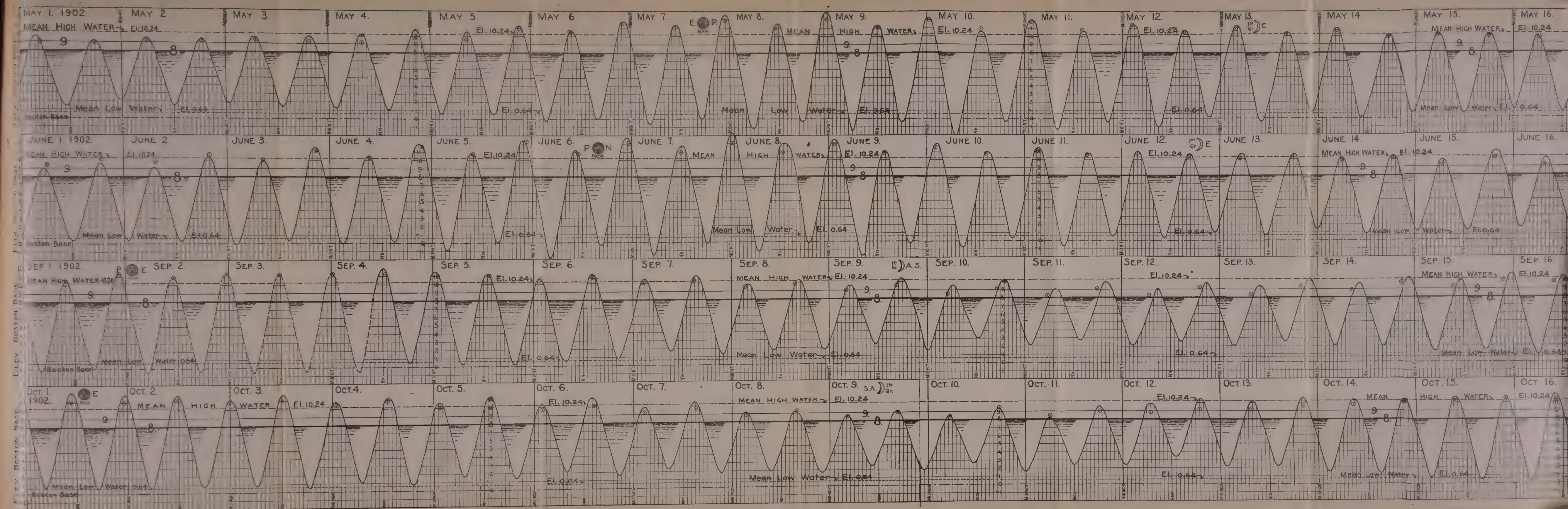
* The Charlesbank wall, which is probably the best of the Charles River sea walls, of coursed granite (built in 1885–6) is 13.1 feet high from bedstone to capstone inclusive, and is built on piles and platforms, at an average cost of about $65 per lineal foot. The presence of ledge and trouble about short piles added some to its cost. On the other hand, there was some saving by the use of stone from old walls, and in comparison with to-day the cost of labor is higher, while stone and cement are cheaper, so the cost can still be used as a fair guide for a wall of equal quality.

The coursed granite wall between Cambridge bridge and Harvard bridge, and now extending up stream from Harvard bridge, built in 1888, has top at elevation 15.5 and bottom at elevation — 2.0, Boston base, and rests on gravel filling without piles; has a riprap front slope. This has cost about $30 per lineal foot.



MAY 1. 1902
MEAN HIGH WATER
El. 10.24
MAY 2.
MAY 3.
MAY 4.
MAY 5.
MAY 6
MAY 7.
MAY 8.
MAY 9.
MAY 10.
MAY 11.
MAY 12.
MAY 13.
MAY 14.
MAY 15.
MAY 16.
MEAN HIGH WATER
Mean Low Water
El. 0.64
Boston Base
JUNE 1. 1902.
JUNE 2.
JUNE 3.
JUNE 4.
JUNE 5.
JUNE 6.
JUNE 7.
JUNE 8.
JUNE 9.
JUNE 10.
JUNE 11.
JUNE 12.
JUNE 13.
JUNE 14.
JUNE 15.
JUNE 16.
SEP. 1 1902.
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OCT. 1. 1902.
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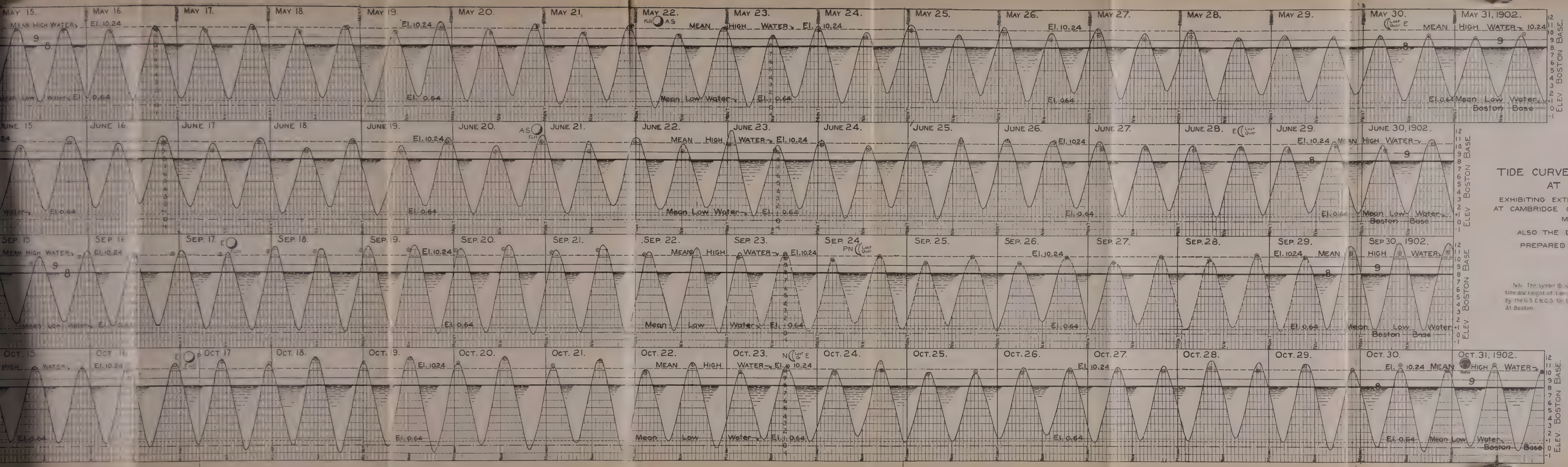
OCT. 16.
ELEV. BOSTON BASE



Note. The symbol ⊙ shows the time and height of tide predicted by the U.S.C.&G.S. for these tides at Boston.

TIDE CURVES OBSERVED BY RECORDING GAUGE AT CHARLESTOWN NAVY YARD

EXHIBITING EXTENT AND DURATION OF LESSENED WATER LEVEL AT CAMBRIDGE CANALS IF PROPOSED DAM IS BUILT AND LEVEL MAINTAINED AT GRADE 8 OR 9.

ALSO THE DURATION AND EXTENT OF GAIN IN DEPTH.

PREPARED FOR COMMITTEE ON CHARLES RIVER DAM
DECEMBER 1902.

JOHN R. FREEMAN, C.E.
ENGINEER TO COMMITTEE.

Disadvantages.

The only important disadvantages that would result from this dam appear to be: —

First. The extra cost (if any) of the dam and its auxiliary structures above the cost of the structures that will be required for sanitary and other reasons, if no dam be built.

(It appears that, taking account of the present condition of Craigie bridge; the dredging of foul mud banks; the improvement of the Fens required regardless of the dam; the necessity for filling and diking and draining marshes; the absolute necessity of improving the dirty banks of the upper portions of the estuary, the method of improvement by means of the dam and its auxiliary structures will cost the least of any efficient method of treatment that can be devised.)

Second. The loss of interest involved in an earlier expenditure for the separation of sewage from storm water than would otherwise be demanded.

(It does not appear that any part of the cost of remedying the present unsatisfactory conditions from sewage in the Fens basin or of removing the defilement from the two Stony Brook channels is properly chargeable to the dam. Neither should the cost of a sewer for the Beacon Street houses be charged against it, nor the connection to sewers of sundry privies and stable drains, now emptying openly or leaching into the basin and the Cambridge canals. The work of separation of sewage from storm water was begun in Cambridge two years ago, and the report of the Boston sewer division for the year 1901 strongly recommends that a similar work be begun in Boston, purely on sanitary and economic grounds, almost without regard to the Charles basin. This work of improving the sewers of Boston and Cambridge must be done sooner or later, although no dam be built. The building of the dam will merely stimulate an earlier and more energetic carrying out of the work.)

Third. The greater interference to navigation by ice on a fresh-water basin, in comparison with the present salt-water basin, and possibly, rarely, some increased trouble with ice in the part of the harbor near the railroad bridges below the dam.

Fourth. The compensation or damages that will doubtless be asked for by those owning wharves.

Fifth. Some very small increase in the cost of dredging out certain deposits of gravel for purpose of sale. (This will be far more than offset to the owners by the market afforded for this gravel in the dam.)

Sixth. A very small increase in total amount to be pumped at the pumping stations of the Boston main drainage and the metropolitan sewerage, due to the larger average quantity of storm water that will be stored in the main sewers after that lying below grade 8 can no longer drain into the Charles at low tide, and must, therefore, drain down through the regulator gates into the metropolitan sewers after the storm is over, and immediately be pumped.

I have had a very complete estimate made of this possible storage in the Cambridge system connected with Binney Street, the largest system of all, and find this will involve only a comparatively insignificant expense.

Seventh. The need and cost of flushing the Broad and Lechmere canals. (This has been provided for by means hereinafter described, and, in this respect, the arrangements proposed in connection with the dam will relieve the present unsatisfactory dirty condition of the Broad canal, due to oil sleeks on the basin that come from gas works and from asphalt roofers' waste, and that which comes from storm wash of streets and dirty yards.)

Eighth. The need and cost of special means for circulation in the Fens basin, now produced by the tide. (This can be done better than now by the marginal conduits elsewhere described in this report. Much less circulation will be required than now, after the "foul flow" of Stony Brook is removed from the Fens by the connection of the new "commissioners' channel" with the old 7-foot channel.)

II. *Full Dam* v. *Half-tide Dam.*

I have given careful consideration to this because of the half-tide plan having been favored by certain men whose opinions are entitled to great respect.

I have come to the opinion that the improvements which are most desirable can be accomplished very much better by a dam of full height than by a half-tide dam.

It appears that much more than half of the advantages for pleasure boating and for park development, with neat, attractive water margins, free from wetness, slime and mud, possessed by a basin with slight current, at constant water level, would be sacrificed by a half-tide dam.

For half the time the objectionable current would be as

Cambridge Esplanade, looking toward West Boston Bridge. Flats exposed at Low Tide, July 11, 1902.
Grade — 0 6, Navy Yard = 0, Boston Base.

strong as now. For half the time the upper half of the slope would be as unsightly as now, and there are some dangers to life connected with pleasure boating controlled by a half-tide dam, due to boys in boats or canoes coming too near the overfall, or to direct attempts to run the rapids while fall was moderate.

The benefits of the constant water level near grade 8.0 or 9.0 in preventing the flooding of the marshes, in draining the mosquito-breeding pools and in lessening the height of storm discharge from sewers and drains would be wholly sacrificed by a half-tide dam.

The Back Bay cellars and Cambridge cellars would continue to be flooded by the backing up of sewage in severe storms at high tide, just the same as now.

A half-tide dam would not properly cover the broad areas of objectionable mud flats in Watertown (see map of upper basin); and, indeed, the rise of the tide, as now, to grade 10.4 (saying nothing about the frequent rise to about grade 12, Boston base) would keep these marshes, guzzles and shores wet and slimy; and its fall to grade 5.2 would uncover many acres of slimy, muddy slopes and flats, mainly in Brighton, Cambridge, Watertown and Newton.

Indeed, so far as now seen, the only substantial advantage presented by a half-tide dam is: —

1. It would secure the covering of the mud flats near Harvard bridge and the dirty strips of flats exposed at low water along the present embankment walls.

2. It would prevent uncovering the unsightly, bad-smelling bottom at the upper ends of the Broad canal and the Lechmere canal.

3. The daily flushing of the Charles basin with salt water would have nearly the same effect as now, and permit the separation of storm water from sewage to make slower progress, and permit delay in providing a sewer for the houses on the north side of Beacon Street.

4. It would afford to the shipping the same flood tide depths as now, during the week of spring tides, and would prevent some of the grounding with the ebb tide that now occurs.

In brief, it would deprive Newton, Watertown and upper Cambridge of the benefits that it brought to Boston and Cambridgeport.

III. *Location for Dam.*

The best location for the proposed dam is plainly at the present site of Craigie bridge; and a little forethought and ingenuity in planning the prosecution of the work here will

lessen the cost by rendering a temporary bridge during construction unnecessary. Every foot gained in the length of the pool below the dam would be of advantage in manœuvring barges, tugs or other boats before or after passage through locks, more so perhaps with the larger commerce of the future than with that of to-day, therefore all increase of width should be crowded to the up-stream side.

One reason for location at Craigie bridge is the desirability of including the largest practicable area within the basin, so that the storage available for flood discharge shall be a maximum.

A second reason is that economy of operation of the drawbridge, the lock, the sluice gates and the possible future propeller pumps at the outlet of the marginal conduit for receiving sewer overflows and street wash can be gained by serving all of these from one power station and under one superintendent.

But the chief advantage of the location at Craigie bridge is that *the cost of the dam itself can be wholly saved to the cities* of Boston and Cambridge and Somerville by utilizing it as the substructure for a new bridge.

The present Craigie bridge is an old structure. I find by inspecting it from above and from a boat beneath that the marks of decay are very apparent, and it is plain that it must soon be rebuilt, regardless of what is done about the future water level of the basin. The present standards of municipal engineering and architecture would probably not tolerate another plain, crude, pile-and-stringer structure like the present, which is simply a restoration or patching up of the bridge of 1808, and the large and increasing traffic over it demands more width.

Some testimony upon the cost of each of the three modern bridges built across the Charles during the past few years was presented at the hearings, from which it plainly appeared that the cost of a modern bridge, including piers and abutments and draw-span, would be considerably greater than the entire cost of the dam, with its regulating gates, wasteways and lock; and the steel bridge would be much less permanent in character than the dam, and, therefore, subject to greater maintenance charges than the dam, by reason of rusting, repainting, repairs and allowance for ultimate renewal.

In order to obtain more definite information upon this question of cost of bridge *v.* dam, the city engineer of Boston was requested to prepare a definite estimate of the cost of the new bridge soon required.

Hamburg. Alster Basin. Lombardsbrücke.

Craigie Bridge—Type of Structure.

He prepared approximate estimates based on three different designs, as follows, and stated that "the general condition of the [present Craigie] bridge is poor and nearly beyond repair:"—

For a steel girder, deck bridge, 70 feet wide, stone piers and abutments, steel draw of double retractile type, roadway grade 23.0, head room at draw above mean high water 7.5 feet, ...	$864,430
For steel bridge, same type, 100 feet wide, . . .	1,148,458
Same as last, with more head room (23 feet above mean high water), grade at draw 38.5, ...	1,463,362
Ornamental steel bridge with stone piers, same width and grade as last, ...	2,044,687

For these estimates in detail, see Appendix No. 13.

The estimate of Mr. F. P. Stearns, chief engineer for the Joint Board of 1894, of the cost of a dam 100 feet in width, "located 600 feet above Craigie bridge, where the river is not more than 1,100 feet wide," including lock, power house and all appurtenances, was $660,000.

The estimate of Mr. Percy M. Blake, C.E. (evidence, p. 238, bottom of page), — made for the proponents in January, 1902, for a similar dam, located at Craigie bridge, without the tidal sluices (which Mr. Blake did not recommend and which I believe are unnecessary), and with a width of 120 feet "made to serve the purpose of a bridge,"— was $1,075,000.

I have prepared estimates for three different types of dam, described in Appendix No. 19, and find that the cost of dam complete with deep lock, sluices, spillways, drawbridge, pavements and all necessary accessories, will be anywhere from about $1,000,000 to about $1,550,000, according to the elaborateness of the type of structure adopted. From an examination of the site, from knowledge of the substrata derived from borings at the site of the old Lowell freight bridge a few hundred feet down stream, and from the studies of the geologist, I am satisfied that the construction at this point is entirely feasible; and, all things considered, including depreciation and repair, the dam and bridge and lock combined would probably cost but little, if any, more than the equivalent bridge 100 feet in width.

IV. *Elevation of Water Surface.*

The requirements of navigation and of landscape effect make it desirable that the level be as near the present mean high-water level as practicable.

If grade 9 is permissible, instead of grade 8, this gain of a foot in height, by lessening the depth of dredging required in the Cambridge canals and near to wharf walls in other parts of the basin, would greatly lessen the danger of undermining those walls during the process of dredging, and perhaps would make it practicable to make the base secure by sheet piling, or other means, and so to a large extent render unnecessary any such general, immediate rebuilding as is set forth in Appendix No. 12.

Grade 8 was the grade that had been established for the Fens basin some years before as the most suitable, under the conditions then existing. The reasons for the fixing of the water level of the proposed Charles River basin at grade 8, Boston base, by the Joint Board in 1894, are quite fully stated on pages xiv–xv, also on pages 26–28 of their report.

One reason was to avoid flooding the up-river marshes; another, to favor the existing sewer systems; another, to make it easier to depress the railroad in Cambridge, for the separation of grades; perhaps the main reason was to make sure of not raising the ground-water level.

It appeared that the existing ground-water level *in the filled lands* adjacent to the proposed basin, except as controlled locally by sewers, was at slightly below grade 8.0. This, moreover, appeared to be about the natural elevation of the water table in this region a short distance back from the shore. The lowest cellar level permissible under the city ordinances is grade 12, four feet above this height.

It must be remembered that, at that time although only nine years ago, the immediate cause of malaria had not been discovered, and more importance was given to mere dampness of the soil as an unsanitary condition than would be attached to it to-day. That certain of the most famous seaside health resorts, located in a climate warmer than that of Boston, have ground water nearer the surface than this, appears by the statement of Lieut.-Col. W. A. Jones, Appendix No. 8, p. 374.

The recommendation of the Joint Board was safe and conservative in that the level recommended for the basin would make the level of the ground water no higher afterward than before the dam was built.

There are some conspicuous advantages in raising the basin level above grade 8, perhaps even to grade 9, and it is, to-day, a fair question whether a higher level than grade 8, Boston base, is not permissible. *The including of marginal conduits in the recommendations and estimates presented herewith will add to the safety in raising this water level.*

The feature now mainly controlling or limiting the height of the water appears to be the possible increase of dampness in cellars; and the lowest permissible level for a cellar bottom, according to the Boston ordinances, is grade 12.

The test wells and other investigations of the chief engineer of the Joint Board led him to conclude (p. 27, report of 1894) "for the Back Bay region of Boston *the height of the ground water is controlled for the most part by leakage into the sewers* and not by the height of the water in the Charles River."

I had hoped to find time to sink similar pipe wells for testing the level of the ground water in various parts of Cambridge near the river and the canals, and in the upstream territory along the narrower portions of the river; but, as already stated, the reasoning on this subject advanced by Mr. Stearns in the hearings before the Harbor and Land Commissioners appeared so conclusive that, in order to give time for other investigations, this work was deferred to the last, and finally had to be left undone.

I do not share the fears mentioned by certain of the experts in the recent hearings that the basin at grade 8 would seriously affect the inland water table, but consider that Mr. Stearns's general propositions regarding the influence of the basin level upon the ground-water level are almost sure to be applicable along the shores of the basin, viz.: —

(*a*) That natural ground-water level is nowhere materially below grade 8 except where lowered locally by drainage of sewers; and conversely, that a basin at grade 8 will not materially raise the present level of the ground water.

(*b*) That the leakage into the sewers controls this level of the ground water, a little way back from the shore, much more than does the water level in the Charles.

The capillary attraction, or the height to which wetness will rise in a porous earth, is almost entirely a question of the fineness of the material. The filling up and grading of the Back Bay lands was done almost entirely with a *loose, moderately coarse, open-grained gravel, in which capillary action would suck up the water or the dampness but very little, probably not over an inch or two;* and with the water of the basin at grade 9 there is no reason to think that the three feet then intervening between the water table and the cellar bottom, in the region close to the basin, would be insufficient. Farther away from the basin the sewers would mainly control the ground-water level.

Raising this basin level from 8.0 as formerly proposed to 9.0 as now suggested would not increase the flood level at high tide, for it is assumed that, in case of great storms, the basin would have been previously lowered or held down to grade 8. The Charles is slow to rise, and it is a matter of record that *in the great Charles River flood of 1886 the peak of its flood did not come along until about two days after the peak of the Stony Brook flood had passed.*

The marginal metropolitan sewers built since the report of the Joint Board of 1894, and the marginal conduits now proposed, also will have material influence in preventing a rise of the ground water behind them.

I am, therefore, led to recommend that it be made permissible to establish the ordinary constant water level at any point between grade 8 and grade 9, as further investigations may determine to be best; and recommend that the spillway be designed with changeable flashboards, so that practical test may be made on the ground-water level, after the dam is built, by first holding the basin at grade 8 for a few weeks and then at grade 9 for a few weeks or months, suitable pipe wells to be previously driven and observed under various conditions, spring and autumn.

V. *Fresh-water Basin v. Salt-water Basin. Comparative Advantages.*

Many persons have the idea that a salt-water basin is more healthful, and that the mere presence of salt in the water of the basin would tend to prevent or retard the decay of any putrescent matter that might enter it. The statements of Dr. H. O. Marcy (see report of evidence at hearings of 1894, pp. 27, 30) reflect the prevailing view.

In order to meet this, the proponents at the hearings of 1902 gave much attention to the feasibility of providing large tidal sluices in the dam.

I had some predisposition to favor a clean salt-water basin on anything like equal terms, particularly after having observed the pleasure of the children bathing and learning to swim at the Captain's Island playground; but a preliminary study soon led me to conclusions so different from the popular view, as expressed above, that I requested the pathologist, the biologist and the chemist each to take up this question from his own field of view, and to make his investigations independently of his associates. *Each of these experts independently reported that, in his opinion, the fresh-water basin would prove the better.*

If absolutely pure ocean water could be had in the Charles and kept free of pollution, a different conclusion might have been reached; but this is plainly impossible, and the varying quantity of upland water precludes a brackish basin of the constant salinity requisite for the best development of marine life.

The chemist, Mr. H. W. Clark, in order to answer this question of the comparative merits of fresh and salt water, undertook several lines of experimental work, which will be found described in some detail in Appendix No. 4. The principal results were as follows: —

(*a*) It was found that, temperature and other conditions being equal, *salt water holds somewhat less oxygen in solution than fresh water*, and therefore, volume for volume, fresh water can receive the greater volume of pollution without the exhaustion of this oxygen, if bacterial life is of equal vigor in each case (p. 272).

(*b*) Several lines of experiments were undertaken for determining the effect of mixing various definite percentages of sewage with fresh water and with salt water, the aim being to learn how large a percentage of sewage could be mixed with each, under various conditions and for different lengths of time, without exhausting the oxygen primarily present in this water and without producing odors from putrefaction (p. 270).

The first series of experiments were made with the mixtures in large, tightly stoppered bottles, which were "incubated" and maintained at a constant temperature of 80 degrees F. for five days, in order to give very favorable conditions for decomposition. The simple test of smelling of the respective samples, from time to time, gave strong presumptive evidence in favor of the fresh water; but, as a means of accurate demonstration, careful measurements of the percentage of oxygen remaining in the water of each test bottle were made frequently, because it is when the free oxygen originally dissolved in the water becomes nearly or quite exhausted that putrefaction with its offensive odors chiefly begins.

In every case and with all the various percentages of mixture it was found that the oxygen disappeared very much more rapidly in the salt water than in the fresh water.

Other similar tests were made, in which the test bottles were left unstoppered, in order that the surface of the water might be open to the air and free to absorb new oxygen from it. The open bottles did not develop such offensive odors as the closed bottles, but *the odors from the mixture with salt*

water were in all cases decidedly the worse; and in general, throughout the variety of experiments performed on comparative mixtures of sewage with fresh water and with salt water, it was found that while when first mixed the faint sewage odor was most noticeable in the fresh water, this odor generally became less, while with sea water mixtures the odor invariably grew worse with time (see pp. 272, 291, Appendix No. 4; also p. 342, Appendix No. 6).

Another series of experiments was made on the comparative merits of salt water and fresh water for taking care of the pollution found in certain of the mud banks of the Charles. Equal quantities (2 grams) of the polluted mud from the Charles were shaken up with equal quantities (½ gallon) of fresh water and salt water in stoppered bottles, which were then incubated at a constant temperature of 80 degrees F. for five days, after which portions were siphoned off for dissolved oxygen determinations.

This experiment was made in duplicate, salt and fresh, with 9 different samples of mud taken from the most polluted mud banks of the Charles and the Fens. *In every case the incubation in sea water exhausted more oxygen than incubation in fresh water, and also exhausted a larger proportion of the oxygen originally present.*

A period of reincubation was then tried on the same samples, by adding one gram more of the respective samples of mud to each bottle aerated again, stoppering and incubating for ten days at 80 degrees F. After ten days the quantity of dissolved oxygen remaining in each sample was tested again, and it was found that in every case a larger proportion of the oxygen was exhausted from the salt water than from the fresh. The odors of the various samples of water were noted after the first incubation and also after the second incubation, and *in every case the salt water had the most offensive smell.*

The lesson from this series of experiments is plainly that the polluted mud flats of the Charles and of the Fens are more likely to rob the water immediately over them of this dissolved oxygen, and more likely to give rise to offensive odors, if the basin is filled with sea water than if it is filled with upland water.

The chemist also prepared a series of laboratory tests in glass tanks 18 inches deep for comparing the bacterial growths in sea water over polluted mud, and in fresh water over the same kind of polluted mud, all mud being taken from the bed of the Charles River. Some of these experiments were continued four weeks, test samples for bacterial counting

being frequently taken. It was found that of the anaerobic growths, which are the ones which produce putrefaction, the greater number occurred in the sea-water tanks, both in the water and in the mud, and the greatest exhaustion of oxygen occurred in the sea water.

My observations upon the deposition of sludge going on continually in the outlet of the new Stony Brook channel and an examination of the vast foul sludge banks now found in the salt Fens basin, and also observations upon some of the smaller sludge banks that now exist near certain of the sewage outlets along the salt Charles basin, prompted a request that the chemist investigate the effect of salt in the water upon throwing down any suspended pollution or turbidity to the bottom as a sludge.

The results of these experiments are briefly reported on pages 286, 287 of Appendix No. 4, and are particularly well shown by the photographs of the samples compared.

It was found that the presence of salt in the water had a strong influence as a precipitant of such matters as Charles River mud and sewage pollution; and, while the effect of this precipitant would be to make the surface water of these large basins more clear, it at the same time concentrates the polluting particles into sludge banks, which are less easily acted upon by those bacteria or other growths which produce inoffensive, odorless decomposition, and in these concentrated mud banks there must be more of a tendency to putrefy.

In the present condition of the Fens basin and its sludge banks, with bubbles arising from them, may be found a most instructive example of the way that sea water acts upon polluted fresh water.

The biologist also made some experiments on the effect of mixing the same proportion of sewage with upland water and with salt harbor water. These are very briefly described on pages 341, 342 of Appendix No. 6. He found that "*under identical conditions, sewage introduced in fresh water was less offensive than when introduced into water from the Charles estuary or the harbor.*"

The biologist admittedly approached this question of the fresh-water basin *v.* a salt or brackish water basin with some bias in favor of a basin containing a considerable percentage of salt water mixed with the fresh water, expecting, from some of his previous experiments, that a brackish-water basin would support the maximum quantity of organic life, and that therefore its contents would absorb or devour a maximum pollution, or plant food, without the production

of offensive odors; but soon after beginning his studies he reported unsurmountable obstacles to the success of this brackish-water plan.

(*a*) That the sea water entering the harbor from off Boston Light, being largely from the cold northern ocean current, was more nearly sterile than the warmer water of points south of Cape Cod, with which naturalists had made the most observations and experiments; and that therefore this water from Boston harbor would be less immediately available for absorbing the impurities and rendering them innocuous, through appropriate bacterial action.

(*b*) That the varying rate of flow of upland water would make it well-nigh impossible to preserve the uniform degree of salinity necessary for the most favorable growth and activity of organic life; that, with violent changes of salinity, many of the beneficent low forms of life would be killed off.

(*c*) That it was not practicable to secure such thorough mixture of the fresh upland water with the salt harbor water as to avoid differences of specific gravity which would prevent vertical circulation, and thus prevent water in the lower layers of the basin from coming into contact with the air, whereby their dissolved oxygen could be renewed.

The biologist found his main field for demonstration in the Fens basin itself. In the contents of this basin, which are about three-quarters salt harbor water, he found that, notwithstanding the motion of circulation is more rapid than it would be in the proposed Charles basin, the salt-water layers remained beneath the fresh-water layer; that vertical circulation and reaeration of the lower layers of the water were thereby cut off, and that these deeper layers were devoid of oxygen, and populated almost solely by the anaerobic or putrefactive bacteria, and would in warm weather continually give off hydrogen sulphide and other foul-smelling gases (see p. 326, Appendix No. 6).

The pathologist (p. 113, Appendix No. 1) reports that the malarial mosquito breeds most freely in fresh water, rarely in salt or brackish water, — which would appear an argument in favor of a salt-water basin; but, after carefully weighing the probable results of changing the Charles from a salt-water estuary to a fresh-water basin of constant level, and after making many bacterial tests of the quality of the harbor water, he concluded (p. 129) that "*the introduction of salt water from the harbor will not be needed, and should only be reserved as an artificial remedy for extreme, unforeseen conditions.*"

As a result of these carefully formed expert opinions, and

View of Charlesbank, 1886, immediately after completion of sea wall.

Charles River Embankment and Gymnasium, 1903.

from conference with other engineers who have had opportunity for observing the effect of sewers discharging into salt water; and from the reported fact that a marked difference is noted in the odors arising from the man-holes of the Boston main drainage and metropolitan sewers to which some proportion of salt water has been admitted, in comparison with the man-holes of the common sewers that receive no salt water; and from such investigations as I have been able to make upon the formation of the present sludge banks in the Charles basin and in the Fens; and from the broad common-sense view that any such varying percentage of salt as would of necessity follow the varying inflow of fresh upland water must interfere with the activities of organic life; and that, of necessity, an imperfect mixture with different specific gravities at the top and bottom would bring defective vertical circulation, and therefore defective oxygenation, and that from this there would of necessity follow a tendency to putrefaction, with its offensive odors, — *the conclusion has been reached as clear, beyond doubt or question, that the fresh-water basin will be very much better, under the circumstances; and that by means of a marginal conduit and other means proposed for lessening pollution, this water at Captain's Island and other future points available for bathing can be kept cleaner and more wholesome than it is to-day, even on an incoming tide.*

As stated on p. 47, and also on p. 145, Appendix No. 2, it appears more hopeful to absorb, devour and render the entering pollution inoffensive by means of the activities of organic life, very much as manure or plant food is absorbed in the garden, than to salt this water, and thus precipitate, concentrate and defer the oxidation of the impurities.

VI. *Necessity for Large Tidal Sluices.*

That these are unnecessary for preserving the sanitary condition of the water of the basin is practically settled by the answer to the last question; and proof that the storm flood sluices included in the present design are ample to prevent the basin from rising to a dangerous or inconvenient height, will be presented later.

That there is no necessity for a tidal sluice as a means for preserving the tidal scour of the channels of the harbor is shown by the statements to be found in Appendices Nos. 8, 9, 10 and 11.

These large tidal sluices, if of the design presented on pp. 272, 273 of the evidence of 1902, would be subject

to rapid corrosion, possibly accelerated by electrolytic action under the influence of fresh or brackish water on one side and salt water on the other; and the expense of maintenance and renewal, as well as their great original cost, makes it desirable to omit them.

It will be found that the sluices provided by the Joint Board of 1894, and also the storm sluiceways provided under the present plans, are ample to change the water in the basin, should it ever become necessary because of too luxuriant a growth of algæ.

VII. *Present Condition of Fens Basin. — Analogy to Proposed Charles Basin.*

Appendix No. 3 is devoted to a study of the facts on which the answer to this question depends. On pp. 41, 42, there has already been given a brief summary of the results of the investigations concerning the present condition of the Fens basin. It was found foul and offensive, but the cause was plainly the continuous pollution of Stony Brook by brewery wash, dry-weather sewage and the overflow from the sewers flushed out in time of storm. A deep, wide-spread deposit of foul sewage sludge now covers nearly the whole bottom of the Fens basin, and has filled up 25 per cent. of its total volume, and the deposit is still going on.

The recent distinctly offensive conditions began with the extension of the new Stony Brook conduit up stream in 1897, in a way that *brings the continuous discharge of polluted fresh water of the brook into the salt-water basin of the Fens.* This precipitates much of the pollution in the form of a sludge on the bottom of the down-stream mile of this conduit, and within the Fens basin.

The lighter fresh water mostly floats on top of the heavier salt water; the salt water remains at the bottom; its dissolved oxygen quickly becomes exhausted; the beneficent aerobic bacteria cannot work in it; the sludge is left to the action of the anaerobic bacteria, which produce putrefaction and lead to the evolution of foul-smelling gases. Such are the conditions that now prevail in the Fens.

The Fens basin presents no true or reasonable parallel to the Charles basin as now proposed, because: —

1. The proportion of pollution entering the Fens to the water contained therein is larger than that entering the Charles as a whole.

2. The removal of a large part of this present pollution is proposed to be made a "condition precedent" to the building of the dam.

3. It is not proposed to reproduce the salt-water conditions of the Fens in the future Charles basin.
4. The aeration of the broad, exposed Charles basin, under the influence of the wind, would be much greater than that of the narrow, sheltered Fens basin.

The biologist, who was asked to give careful attention to the analogy between the Fens and the proposed Charles basin, reported (p. 316, Appendix No. 6): "The Fens basin . . . affords, in my opinion, no fair or proper standard by which to judge the proposed Charles basin." And again, on p. 330, he states, in substance, that the conditions in the proposed basin will be so superior to those in the present Fens basin that little real similarity will exist.

VIII. *Quantity of Upland Water.*

This is fully discussed in Appendix No. 16. We have no good reason to suppose that, under ordinary conditions, this will be very different from the estimates already made by Messrs. Stearns, Blake and others, which were based on assuming the flow per square mile of water-shed to be the same for the Charles as for the Sudbury; but in summer droughts the flow will often be less than this, because of interference with natural flow by holding back the water in the large mill pond of the Boston Manufacturing Company at Waltham.

It is found that the Charles is a river of remarkably uniform flow, and that the freshets on it are exceptionally slow, and small in extreme height, as compared with nearly all other New England streams. The rise comes slowly, is not high, and takes a long time in running past.

IX. *The Purity of this Upland Water.*

This was carefully investigated by the chemist, and a series of analyses upon it will be found on pp. 242–248 and 252–254 of Appendix No. 4.

Many samples of this water were collected and analyzed during September, October and November, some of them at times of a moderate drought, when, because of the factory wastes being nearly constant, the relative pollution is larger than at times of larger flow.

An abundance of free dissolved oxygen was found in the water at all times, and this shows its large capacity to support the microscopic life, — bacteria, diatoms, algæ and minute crustaceans, — through the life and activity of which

the polluting material is absorbed, rendered harmless, and made available as a food supply for plants and fishes.

The proportion of organic matter shown by analysis in this upland water at nearly all times is no larger than found in some fairly satisfactory public water supplies; but in times of drought the pollution and discoloration from the dye houses, and other factory wastes, is very noticeable, and there are times of small flow when no water is flowing over the factory dams in which the concentration of street dust and floating rubbish, skimmed off and concentrated in the pools immediately above the factory dams, give an unsightly appearance to small areas. Although the dye-house wash water is sometimes alarming in appearance, the analyses show that the actual quantity of deleterious matter in it is very small. The high coloring matter becomes quickly diffused.

There is a good opportunity at most of these factories to divert any really foul flow of wash water into the main metropolitan sewer, and the wash from wool-scouring at the factory at Bemis is reported to be largely diverted into the sewer at present.

Incubation tests were made on many samples of this upland water, by exposing the samples of water, in large, stoppered bottles, to a temperature of 80 degrees F. for five days. Some samples reported on p. 270 of Appendix No. 4 were collected at a time when the flow of the river was exceptionally low (September 22, probable flow, about 35 cubic feet per second), at about the close of one of the dryest and warmest periods of the present year. These tests showed that, although this water contained, at most, dissolved oxygen to only 30 per cent. of saturation, and in some cases much less, in only a very small proportion of these samples was there present sufficient impurity of an easily oxidized nature to exhaust the oxygen in this severe test.

Bacterial examinations were made of many samples of this upland water (see pp. 281, 285, Appendix No. 4; also p. 123, Appendix No. 1). The number of bacteria per cubic centimeter of the water was found decidedly less than the average number of bacteria in the Merrimack water at Lawrence.

The biologist also gave careful attention to the quality of the upland water (see Appendix No. 6, p. 335), and found this favorable for its remaining nearly stagnant in the proposed basin during long periods if need be, and also found that the proportion and kinds of micro-organisms con-

tained in it were favorable for the disposal of considerable quantities of pollution.

The biologist reported orally that this upland water was nearly always found in excellent condition, and that the large volume of storage contained in the proposed basin would so dilute any relatively high discoloration or pollution during summer droughts as to make it unnoticeable.

The quality of this upland water was also investigated carefully by the sanitary engineer (see Appendix No. 5, pp. 308, 309). He finds that the considerable pollution received near the head of the stream in Franklin and Milford is nearly all absorbed, and disappears during its sluggish flow through many miles of sparsely settled country; so that, when the river water reaches Newton Upper Falls, near the intakes of the Brookline and Newton water works, the water is clean and well suited for domestic use. At Newton Upper Falls a few small factories pollute it, and a slight increase of organic matter is found in the analysis of samples from near the intake of the Waltham water works. Below the Waltham dam some more factory wastes enter.

The chemist sums up the results of his analyses of this upland water by saying (p. 289): "This water is low in color, practically odorless, and, with the exclusion of some of the wastes entering below Waltham, would be suitable for a public water supply, as far as organic matter is concerned;" and that, with stagnation in summer in the proposed basin, the continual oxidation would cause the quality of this upland water to continually improve.

X. *Present Pollution of the Charles River Basin, and Means of lessening this.*

The obtaining of a reliable estimate of the quantity of polluting material was found to be the most complicated, puzzling and difficult of all of the subjects investigated; and the importance of this matter to the whole plan was such as to forbid leaving the subject until the conclusions were established within reasonable limits beyond possibility of mistake. In Appendix No. 2 it has been sought to describe, in the briefest intelligible form, the scope and methods of the investigation and their results.

The pollution is, beyond doubt, now greater than it was expected to be in 1894, after the completion of the north metropolitan sewer; mainly because of admitting the dry-weather flow of Stony Brook directly to the Fens, and be-

cause the sources of pollution in the Stony Brook valley have rapidly increased.

The recent investigations have brought to light a serious cause of offensive pollution in the flushing out of deposits and accumulations of filth from sewers by the rush of flood water in time of storm; but the percentage of the total sewage which escapes in time of storm into the Charles basin and its tributaries through the sewer overflows is found to be only about half as great as seemed probable from the evidence presented at the public hearings of 1902 (3 per cent., instead of 7).

After a very exhaustive examination into the conditions under which the sewer overflows discharge their surplus of mingled sewage, street wash, roof water and surface drainage into the Charles and its tributaries in time of storm, it was concluded (see table inserted at p. 183, Appendix No. 2; also p. 50, engineer's report) that, under present conditions, but allowing for the changes soon to be brought about by the completion of the high-level sewer, the amount of this sewage overflow will surely not exceed the ordinary constant sewage flow from a population of 10,000, and will perhaps be not more than half this. The most probable equivalent population is about 6,000 to 7,500. It is to be constantly borne in mind that the actual discharge is intermittent and not well diffused and therefore would be more difficult to deal with than the same quantity discharged at a constant rate; but, on the other hand, the diagrams at p. 188 of Appendix No. 2 show that this overflow discharge comes mainly in the cool months, before pleasure boating begins.

The proposed marginal conduit at Binney Street will, in ordinary storms, divert about 18 per cent. of this pollution; and that on the Boston side, if carried only to the Fens outlet, will, in moderate storms, divert about 50 per cent. more; and, after the marginal conduit has been extended to St. Mary's Street, perhaps 15 per cent. additional, in all moderate storms.

After the new high-level sewer is put into use, the Charles River valley sewer will be no longer backed up from the Boston main sewerage, and will have a surplus capacity for some years to come, save on comparatively rare occasions. Therefore, under the plans now proposed, the only pollution entering the basin will be the street wash, and the overflow from sewers in the west end of Cambridge, the discharge from which will become less as the separate system is gradually extended. In severe storms, and for two or three hours at high tide, the marginal channel cannot carry all the overflow, and some dilute sewage will continue to be discharged into the basin; but at such times the upland water available for dilution will also be increased.

The probable extension of the separate system in Boston will tend to lessen frequency of overflow, and a greater rainfall will be required before overflow occurs. This gradual improvement will offset any

increase due to increased population, and the improvement of the two Stony Brook channels and the removal of the sewage now entering them will lessen the chance of a nuisance at the outlets of the marginal conduits, just below the proposed dam.

The means for lessening the present pollution are obvious and simple, and relief from a part of this pollution is already in sight, regardless of the proposed dam: —

(1) The pollution of the new channel of Stony Brook will be greatly lessened by the projected progress of this channel up stream during the next two years, and by the simultaneous construction of the large low-level sewer which is being built in combination with this Stony Brook conduit. This new sewer can at once take in the brewery waste and much sewage that now defiles the brook, and at the same time will provide for the probable future rapid increase of sewage in this region.

(2) The new high-level sewer now under construction, and which will be completed two years hence, will greatly lessen the quantity of sewage overflowing.

(3) A sewer will probably soon be constructed for the Beacon Street houses, so that they will no longer discharge their sewage directly into the basin.

(4) A careful sanitary inspection should be made along the tributary streams, and the privy drainage and factory waste, gas works waste and oil in condensation water should be diverted into sewers.

(5) The old Stony Brook conduit should be improved by diverting considerable sewage which now enters it into the sewers; and the present tumbledown structure, with its roughness and hollows, in which the sewage sludge finds lodgment, could be replaced by a smooth, clean, modern structure, designed primarily for the interception and conveyance of storm drainage from the streets and catch-basins.

(6) The dry-weather flow of Stony Brook that now comes down through the commissioner's channel into the Fens should be diverted by a short piece of conduit into the old 7-foot by-pass channel, leading now into the Charles River, but in future into the proposed marginal conduit.

This short and comparatively inexpensive piece of conduit should have been built five or six years ago, and would have prevented a large part of the recent defilement of the Fens basin.

(7) The sludge banks that have accumulated in the Fens should all be dredged out so as to give the original depth of 8 feet of water over all parts of the basin, excepting its steeply sloping banks.

From the plan of soundings given in Appendix No. 3, it will be found that the present volume of sludge may amount to 70,000 cubic yards; but, since there is some uncertainty in these measurements as to the dividing line between sludge and the original mud bottom, I have conservatively estimated this quantity as not less than 50,000 cubic yards.

This dredging could probably be most cheaply done after the completion of the dam and the opening of a broad passage way between the Fens basin and the Charles basin, through which scows could pass, since by this means the twice handling of material could be avoided; or it would be possible to remove it now in substantially the same manner that was followed in the dredging of 1895, by means of a hydraulic dredge, from which it could be discharged into the 7-foot channel, and again intercepted and redredged from the bed of the Charles near the Fens outlet, or flushed down through the marginal conduit and dredged out below the dam.

(8) There are three sludge banks in the Charles basin, each of comparatively small area, and probably in no case more than 2 or 3 feet in average depth, from which it may be advisable to dredge the sludge. These are located (1) near the outlet of the Binney Street sewer, (2) near the outlet of the Fens basin, (3) at the starch factory drain near the Brighton Abattoir. These can doubtless be cheaply removed while securing filling for the proposed marginal embankment, since the chemist's analyses show that the percentage of organic matter in the mud forming these banks is so small that they can doubtless be utilized for filling if deposited in a place where they will be deeply covered.

XI. *Amount of Pollution Admissible without Offence.*

The studies of the biologist, of the chemist and of the sanitary engineer were particularly directed to obtaining the fullest and most up-to-date information on this point that was possible in the time available.

Within the past five or ten years there has been a great advance in exact scientific knowledge concerning the means by which, in nature, manure or pollution is made available for plant food; and, while we are doubtless as yet only at the beginning of knowledge in these matters, some of the limitations as to admissible pollution are becoming well understood, and the debatable ground is being continually narrowed.

The biologist (Appendix No. 6, p. 316) says: "It appears to me highly probable that it" (the proposed Charles basin, containing 458,000,000 cubic feet of fresh water, of the quality now found above Watertown dam, refilled in hot weather at least once each one hundred days, and having a surface of 1.27 square miles favorably exposed to sun and wind) "can assimilate the assumed amount of sewage" (equivalent to the continuous ordinary flow from 10,000 persons), "together with the present, and probably the future, amount of street wash, without causing offence."

The following are other quotations from the biologist's report bearing on this question: —

"Just as by experiment in a balanced aquarium the amount of vegetation necessary to balance an excess of plant food could be added, so

in the proposed Charles River basin a growth of algæ would soon become established sufficient to care for such polluting organic material as now comes over the Watertown dam or is likely to enter with the street wash" (p. 340).

And, as to danger from excessive growths of algæ, which by their decay would produce malodorous or unsightly conditions, such as have happened not infrequently in certain storage reservoirs for water supply, he states (p. 339) that, with care given to lessening the pollution and with conditions favorable to the life of organisms that browse on the algæ, trouble from this source appears extremely improbable, although remotely possible.

"While it is true that pollution of water by nitrogenous substances directly promotes the growth of aquatic plants, these same plants do much to justify their existence by producing oxygen (and thus tending to check putrefaction) and by assimilating the nitrified polluting material" (p. 331).

"It is probable that proper precautions may avoid the likelihood of an excessive growth of algæ, which might, in dying, become offensive."

The chemist concludes, as the result of his season's work: —

"It is exceedingly improbable, in view of the results of the experiments given, that all the wastes now entering the basin would, under any circumstances, rob the still fresh water in the proposed basin of its dissolved oxygen" (p. 290).

An extreme outside estimate of the amount of pollution entering the proposed basin at the present time during the six dry, warm months, would not exceed in quantity that contained in the continuous flow of sewage from a population of 10,000 (p. 50, also Appendix No. 2, table following p. 183). Assuming the average per capita quantity of sewage of average composition is 100 gallons (for, although the quantities of liquid found flowing in the sewers of the metropolitan district average more nearly 150 gallons (see Appendix No. 2, p. 171–174) a large part is ground water), and calling the population 10,000, it follows that the equivalent of not more than $10,000 \times 100 = 1,000,000$ gallons per day of ordinary sewage is discharged into the Charles basin under present conditions. The basin contains about 3,435,000,000 gallons of water; therefore thirty days' run of the quantity of sewage estimated on this extreme hypothesis would amount to less than 1 per cent. of the contents of the basin.

The marginal conduits will immediately lessen this quantity, the completion of the high-level sewer will lessen the frequency of overflow along the Charles valley sewer, the extension of the separate system in Cambridge and Roxbury will diminish the volume of sewage entering, and the charts at p. 188 of Appendix No. 2 show that the frequency and duration of overflow is much less in summer than for the yearly average. Therefore, plainly and surely the percentage of sewage in the basin will be smaller than this 1 per cent. found by the estimate of the preceding paragraph.

In our chemist's tank experiments with various mixtures of sewage and fresh water it was found, with a deep stagnant tank exposed to sun and air, in very warm weather, that, with from 4½ to 7 per cent. of sewage added, no characteristic sewage odor could be detected; the water was continuously of good appearance, and in the complete chemical analysis of samples each day, free dissolved oxygen was always found.

The chemist sums up certain of these tests on p. 277, saying, in effect: The mixtures have been made to contain vastly greater proportions of sewage than could occur in the proposed basin, and illustrate: —

First, a state of equilibrium in water containing considerable sewage, if oxygen is present.

Second, that water containing as much nitrogenous matter in a state of change as is found with 4½ to 7 per cent. of sewage added to clean river water, retains its oxygen and does not give off odors.

Third, that 4½ to 7 per cent. of sewage can be added to fairly clean river water without exhausting its oxygen, if the addition is gradual.

Fourth, that bacterial action occurs as readily in still as in moving water, if oxygen is present.

The sanitary engineer, in Appendix No. 5, reports the most instructive series of observations for defining the limits of pollution admissible without offence. These form a valuable extension to the observations made by F. P. Stearns for the report of the State Board of Health in 1890, and reported on pp. 785–793 of the special water supply volume of that year. This brief report of Mr. Stearns, rearranged and paraphrased in various forms, appears to have furnished most of the data for certain of the American authorities in their statements as to the permissible limits of stream pollution. It had the great advantage of being founded upon field observations, concerning the offence, or lack of offence, produced on the senses of sight and smell along a few Massachusetts streams by the discharge into the stream of the sewage from a known population. In order to present the data in convenient form for comparison with other streams, Mr. Stearns supplemented these observed facts by a brief study of the chemical composition of ordinary sewage and of the water supply that became sewage by the addition of pollution, and also added an estimate of the flow of each of these streams.

From scantiness of data, Mr. Stearns was compelled to leave the subject in incomplete form in 1890; but he prudently set his limits of the ratio of population to stream flow that was almost sure to give trouble and of the proportion almost sure to be inoffensive, wide apart. Mr. Stearns found that, when the stream flow averaged less than 2.5 cubic feet per second per 1,000 persons whose sewage was received, offensive conditions were highly probable; and also found that with more than 7 cubic feet per second of stream flow per 1,000 persons there was almost certain to be no offensive odor or offensive appearance produced.

Some authorities have attempted to formulate these matters in terms of number of dilutions required, but, because of the daily gallons of

sewage per capita varying, somewhat like the per capita water supply of different communities, while the per capita quantity of excreta and waste of all kinds is fairly constant, the Stearns formula of cubic feet of stream flow required per 1,000 of population is a much safer guide than a specified number of dilutions.

If we call the Boston sewage 100 gallons per inhabitant per day, or pretty nearly the same as the water supply, omitting the ground water, this lowest limit of 2.5 cubic feet per second per 1,000 population corresponds to diluting 1 volume of this sewage by 16 volumes of fresh water; and the highest limit of 8 cubic feet per second per 1,000 population corresponds to diluting 1 volume of this sewage by 52 volumes of fresh water.

If, as a standard, we take the more common rate of sewage flow as 75 gallons per capita, the corresponding dilutions are 21 and 70. The Stearns data, thus expressed, say that, with only 16 to 20 dilutions, there is almost sure to be offence; while with 52 to 70 dilutions it is almost certain that no offensive conditions will arise.

Samuel Rideal of London, Eng., in his recent treatise on the "Sewage and the Bacterial Purification of Sewage," 1901 (pp. 14–18), speaks of the well-established fact that "the bacteria, always naturally abundant in river water, are able, by the aid of the oxygen dissolved from the air, to oxidize more or less rapidly any ammonia or organic matter that may be present," and bases his conclusions upon the efficiency of this treatment almost wholly on the sufficiency of the free oxygen present.

He quotes Dupré as stating that, "on the average, a dilution of sewage by 30 volumes of thoroughly aerated river water prevents it from fouling and ultimately purifies it." Since the ordinary European sewage amounts to only about 40 gallons per capita, this would correspond to only about 15 volumes of the less concentrated American sewage, and he quotes his own (Rideal's) experience that "even a less proportion has been effectual." He also cites the River Exe below Exeter, Eng., as having a volume of river flow 40 times the volume of the sewage discharged into it, and states that no chemical evidence of pollution was obtainable a few miles below. This, for American sewage, at 75 gallons, would correspond to about 20 dilutions.

Mr. Goodnough's recent work followed the Stearns method, but covered the examination of a very much larger number of streams and included some ponds. The effect of this broader information was to fully confirm the safety of the rules laid down by Stearns, but it narrowed the doubtful ground by raising the limit below which the dilution will probably cause offence from 2.5 to 3.5 cubic feet per second per 1,000 persons, and lowered the upper limit from 7 or 8 to 6; for Mr. Goodnough found that, "*where the degree of dilution exceeds 6 cubic feet per second per 1,000 persons, objectionable conditions have not been produced.*"

The flow of the Charles in all ordinary seasons is much more than sufficient to give this degree of dilution of 6 cubic feet per second per 1,000 persons, and in extreme drought the large volume of upland water in storage will be far more than sufficient to keep the proportion of sewage far below this limit.

The table on p. 312 of Appendix No. 5 is very instructive, and shows that in Massachusetts 14 streams have been observed in which the entering sewage becomes less diluted than the present average sewage inflow to the proposed basin would be without marginal conduits, with no offensive condition produced save in a single case, where one of the largest woolen mills in New England adds wool-scouring liquor to the ordinary sewage of the population.

In other words, *out of 36 Massachusetts streams reported upon by the sanitary engineer, 13 receive and digest without offence a larger percentage of sewage than it appears that the proposed Charles basin could possibly receive from sewage, street wash and all other sources that can be foreseen.*

XII. *Remedies for the Unavoidable Pollution.*

The best remedy is that provided by nature, and found in almost every natural pond and flowing river, the effects of which natural remedy have long been in part recognized but not understood with any degree of clearness until within the past ten or twenty years. This process is substantially the same as that by which the manure applied to the lawn or garden is made inoffensive, and is the same process on which the most efficient modern methods of purification of sewage and purification of water supply are based.

This process begins with bacterial action. These low forms of life, of which from a thousand to fifty thousand individuals are found in each teaspoonful of the water of the upland Charles (see p. 123, Appendix No. 1, and p. 281, Appendix No. 4), seize on this pollution as their natural nourishment, or, speaking as a chemist, they oxidize it, nitrify it, break it up chemically and transform it into new compounds of different chemical composition, which are directly available for plant food; and on these secondary compounds the algæ, microscopic plants and plants of larger growth find their nourishment; these in turn give food to multitudes of microscopic organisms, crustaceans and others, barely visible to the naked eye, which in turn become food for larger organisms and minute fishes; these plant growths are also browsed upon by the vegetarian fishes, which in turn furnish food for the larger carnivorous fishes.

All of the examinations and tests by the chemist, biologist and sanitary engineer appear to prove beyond any reasonable doubt that the amount of the unavoidable pollution will be no greater than can be readily absorbed and utilized in these processes of nature, and without causing any unsanitary or offensive conditions.

The question of offensive conditions being produced where the marginal conduits discharge below Craigie bridge has given me some concern, and should receive farther study in the final design; but I have come to believe that by the exercise of care and forethought much of the worst of the pollution from the flushing out of sewers in storms could be held in these conduits until the storm was over, and flushed back into sewers. The water flowing ordinarily in the conduits will have its pollution thoroughly diluted and diffused, and at the worst I do not see how any condition can be produced below the dam worse than has been tolerated for some years past in the Fens. The spillways and sluices have purposely been placed close to the outlet of the marginal conduits, so that the full flow of the upland Charles River may aid in the dilution and flushing.

XIII. *Means of circulating Water in the Fens Basin and Cambridge Canals.*

No definite recommendation as to the means by which this circulation could best be accomplished was made in the report of the Joint Board of 1894. The fact that the Fens was not then in such a bad condition as that which developed later, and that the polluted dry-weather flow of Stony Brook was not at that time constantly admitted to the Fens basin, permitted this question of pollution to escape such close attention as now.

One possible method of excluding the foul dry-weather flow of Stony Brook from the Fens would be by a comparatively inexpensive arrangement for controlling its fall into a large branch of the main drainage sewer which passes beneath the new Stony Brook conduit, not far from its outlet. While this might serve as a temporary expedient, there are very evident objections to it as a permanent remedy, both on account of adding a new burden to the main sewer system, which is rapidly becoming overloaded, and also because of the expense of pumping this extra burden of water at the Calf Pasture pumping station, on its way to the reservoirs and outfall at Moon Island.

For producing a circulation of water through the Fens and thus diffusing the pollution brought in, Mr. Percy Blake (evidence, p. 207) proposed a special pumping station, and estimated its cost roughly at $50,000, and that

the annual expense for maintenance would be about $6,000. This maintenance charge, capitalized at 4 per cent., would amount to $150,000, which, added to the $50,000 of first cost, would have made the capitalized total cost of circulating the water in the Fens basin by this method $200,000.

The marginal conduit with one or two inflow weirs located near Stony Brook and Muddy River inflow will obviously accomplish this purpose more perfectly and more cheaply, because, instead of merely diluting and diffusing the pollution, it immediately removes it from the Fens and from the Charles. The primary purpose of the marginal conduit is to remove sewage overflow and street wash; but this extra service of providing circulation will add only a very small amount to its cost, and avoids the objectionable power plant and pumps in the park. There will be an abundance of water for supplying this overflow, even in extreme drought; but if, through leakage or lockage or evaporation, during the most extreme drought the inflow from the Charles and Stony Brook should fail to maintain a surplus, a small volume of sea water could be carefully admitted through the deep sluice to the deep lower end of basin without its general diffusion, and without injury to the organic life of the basin, and be siphoned out again readily through the same deep sluices as soon as there was a surplus flow of upland water.

For providing circulation and diffusion of the foul water of the Broad and Lechmere canals, no remedy was proposed at the hearings of 1894 or those of 1902. To do this by means of pumps would require a large expense in plant and maintenance, and without some means of circulation they would surely become intolerably foul. This circulation and removal of the foul water can, I believe, be satisfactorily performed by means of the inflow weirs and their connection to the marginal conduit, as estimated in Appendix No. 19, and described also on p. 59, engineer's report.

XIV. *Lessening Pollution of Basin by extending the Separate System of Sewerage.*

Newton, Watertown, Waltham and some parts of Brookline are sewered on the separate system, so called, under which system, if complete along all parts of the trunk sewer, there would be no overflow of sewage into the Charles basin in time of storm.

A careful investigation was made of the feasibility and cost of extending this method, and it was found that the

cost of carrying it out in such completeness as to render the marginal conduits unnecessary was excessive; moreover, many years would be required to complete a work of this magnitude.

The work of separating the storm water from the sewage in Cambridge was begun about two years ago, mainly for the purpose of relieving sewers that had become outgrown and to prevent flooding back into cellars, etc., during heavy storms that occur at high tide; and considerable progress has already been made on the construction, but mainly in the large trunk lines. Comparatively few of the Cambridge house connections have yet been changed.

It is expected that this work will go on in Cambridge, from year to year, at such moderate rate as can be conveniently included in the annual tax levy, regardless of construction of the proposed Charles River dam; but if the dam is built, it will naturally not be pushed ahead so rapidly, and some parts may be indefinitely postponed and much expense to the city thereby saved, for the motive for avoiding sewer overflow in heavy storms at high tide will have then disappeared.

In compliance with our request, through the mayor of Cambridge, Mr. Hastings kindly made designs and estimates for completing this separation throughout all that portion of Cambridge tributary to the Charles River, and found that it would require about 76 miles of drains and sewers, for which the cost was estimated as follows: —

For work on the sewers and drains, ...	$787,763
New house connections so arranged as to separate the storm water from the sewage water, roughly estimated at $100 per house, . .	1,123,200
Total, ...	$1,890,983

A supplementary estimate showed that the cost of this separation for all of the Cambridge territory tributary to the Charles, after excluding that tributary to the Binney Street main sewer, whose overflow it is proposed to divert into a marginal conduit, was as follows: —

This was found to require about 48 miles of sewers and drains, the cost of which was estimated at	$507,925
The number of houses in this district is 6,033, for which, at the price of $100 each, assumed above (probably excessive for this class of house), the cost of separating roof water from sewage in the house connections would be	603,300
Total cost of making the change throughout the Cambridge district, excepting that tributary to Binney Street, ...	$1,111,225

It is of interest to note that, *at the cost assumed* for changing house connections, this secondary branch of the work costs more than the sewers and drains themselves, and, coming directly on the house owner, will naturally impede this branch of the work.

The city engineer of Boston, at our request, detailed one of his assistant engineers to make careful studies of the cost of separating the sewage from the storm water on the Boston side of the river in the territory tributary to the Charles. These estimates are reported with considerable detail in Appendix No. 15.

The cost for that portion of the territory lying mainly westward of Stony Brook and the Fens was estimated at	$2,701,000
For the territory lying mainly to the east of the Fens and Stony Brook, the overflow of which can be nearly all diverted into the proposed marginal conduit, the cost would be	2,004,000
It was found that, for an entire district tributary to the Charles, the total cost, including both the work in the street and the changing of the house connections, would amount to	$4,705,000
Adding to this the cost of the complete separation for Cambridge, it appears that the cost of separation for both sides of the basin would amount to about	$6,596,000

This amount is so enormously in excess of that required to lessen the pollution of the basin by means of the marginal conduits, which conduits also remove much of the street wash, that further consideration of this separation of sewage from storm water as a condition precedent to the construction of the dam may be dismissed. Yet without doubt this work of separation will gradually progress, from entirely independent reasons; and, as it will naturally be spread over a long period of time, it will obviously be best to first carry out those portions of the work which lie in the territory up stream from where sewage overflow will be discharged into the proposed marginal conduits, particularly in that part of Cambridge which lies up stream from the Captain's Island playground and bathing beach.

XV. *Effect of Stagnation upon Odor, Appearance and Character of Water.*

The words a basin of "stagnant water" have been used by some of the opponents in a way that appeals to popular prejudice and not to modern science. "*Modern science has reversed the tenet of thirty years ago, and now unhesitatingly affirms that it is quiet water rather than running water that purifies itself.*" *

Stagnation of itself does no particular harm, and still water is not of necessity unsanitary. The ponds on Boston Common and Public Gardens are but stagnant pools. Every reservoir from which Boston, Cambridge, Lynn and Winchester draw their water supplies for drinking and other domestic purposes is a "stagnant" pond, and the great

* From p. 17 of Pittsburg report by Sedgwick; same report cited by Dr. H. J. Barnes, evidence, p. 300, but a little farther along, not supporting his view and not quoted.

artificial lake of the metropolitan water supply will be much more nearly stagnant than the proposed Charles River basin.

The balanced aquarium is maintained with stagnant water.

The main advantage possessed by running water is that the constant delivery insures a constant mixture and completeness of diffusion not attained when pollution is discharged into a pond (and the one difficulty to have been feared, if it had been proposed to get along without the marginal conduits, would have been lack of quick diffusion).

The popular idea as to the superiority of running water as a means of disposing of pollution comes mainly from the fact that by its motion it takes the pollution away and out of sight of the persons or the community that produced it, and they seldom follow down to see what really becomes of it; but, in addition to this, there is even in a slow-moving stream a circulation of the deeper water to the surface which aids in oxygenation to a degree not found in a deep pond, where difference of temperature impedes vertical circulation. The wind-swept surface of the Charles gives ample opportunity for oxygenation.

The popular idea of stagnation attaches more particularly to a pool that is so shallow as to give favorable rooting to vegetation on its bottom, and is at the same time, because of being so shallow, made more warm by the heat of the sun than this deep basin can ever become; a pool filled with algæ, or with shallow, sedgy banks, in which mosquito larvæ may find shelter, like those described on p. 113 of Appendix No. 1. This is something utterly different from the proposed basin, with its deep water, wind-swept surface and clean-walled shores.

The pathologist found no reason for expecting malaria around a large, quiet pond, with clean banks such as are proposed for this basin.

One of the best available items of proof on this question of stagnation is to be found in a study of the Mystic lakes, particularly the upper lake, until recently used for a part of Boston's public water supply.

During nearly ten years' residence at Winchester I was familiar with this, and familiar with the pollution of the stream that entered it and with the marvellous way in which the forces of nature appeared to dispose of this pollution, and this experience has strengthened my confidence in the answer to this question. The chemist refers to this experience with Mystic Lake on pp. 287, 289, 290 of Appendix No. 4.

The chemist (Appendix No. 4, p. 275) made a few laboratory experiments having a bearing on this question of the effect of a gentle motion in the water upon its capacity to dispose of pollution, from which he concluded that "purification by bacterial action occurs as readily in still as in

moving water, if oxygen is present," and on p. 291, in summing up his conclusions, he reiterates this statement in opposition to the popular idea that running water purifies itself more quickly than still water.

The most reliable information on this subject for our present purposes is that derived from natural ponds in comparison with rivers, into both of which known proportions of sewage are discharged; and therefore Mr. Goodnough's collection of new data is particularly valuable at this time.

His conclusion (p. 311, Appendix No. 5), from the experience with the ponds at Easthampton, Attleborough and elsewhere, is that *sewage discharged into a pond or slow-moving stream, such as the proposed Charles River basin, has a less noticeable effect than an equal volume of sewage has* upon a rapidly moving stream of equal volume.

Observation of natural ponds and artificial storage reservoirs has shown that sedimentation and the bleaching effect of the sun have a noteworthy influence in the purification of quiet or stagnant water, in addition to the effects of bacterial decomposition.

XVI. *Effect of this nearly Stagnant Fresh Water on Public Health. — Malaria.*

This question has been largely answered in the preceding pages. Appendix No. 1 is mainly devoted to its discussion in much detail, and, as already stated at p. 47, it appears to be demonstrated that there is no danger whatever of introducing conditions favorable to malaria because of the stagnation of water in the proposed basin.

On the contrary, it appears that by the shore line improvements which become more easily practicable and within economic reach, when the basin is held at a constant level and with the margins of the river sloping and drained so that the present small shallow portions in which mosquitoes now breed will no longer exist, with the pollution of the basin lessened and with no foul mud flats exposed at low tide as now, *there will be a distinct gain to comfort and health in the neighborhood of the river*, that will come directly from the building of the dam and stopping the present tidal ebb and flow.

Although it is yet unproved that the foul smells of the Fens basin or those from the mud flats of the Charles at low tide are producers of disease, they are distinctly unsanitary, by reason of tending to lower the vital resistance, and make life less cheerful and comfortable.

XVII. *Effect of cutting off Tidal Prism upon Shoaling of Harbor.*

This matter is fully discussed in Appendices 8, 9, 10 and 11. *The estimate of shoaling given by the maps presented at the end of the volume of evidence before the Harbor Commissioners in 1894, and also discussed in Massachusetts Senate Document No. 303, 1895, appears to be of very doubtful accuracy, because of lack of completeness and precision in the surveys compared, particularly for the main portion of the harbor*, after excluding the portions immediately adjacent to the outlets of the Charles and the Mystic rivers. Comparing the survey of 1835 (the best survey of all) with the survey of 1861, the survey of 1861 shows a deepening in the same areas where a comparison of the surveys of 1861 and 1892 shows a shoaling.

Since it has often been said that the records show that a shoaling has occurred in the harbor, it is perhaps necessary to briefly refer to those records at this time.

Under chapter 74 of the Resolves of the Legislature of 1895, the Massachusetts Harbor and Land Commission was directed to report "What shoalings have taken place in Boston harbor since 1860," the extent and nature of the deposits, the extent of dredging by federal, State or municipal government, whether to deepen the natural channel or to remove deposits.

They reported in Senate Document No. 303, 1895. Their engineer, F. W. Hodgdon, found by a comparison of the surveys of 1861 and 1892 that there had apparently been a very large and noteworthy shoaling immediately down stream from the Charlestown bridges, and also a large shoaling down stream from the mouth of the Mystic River and Chelsea Creek.

In the main portion of the upper harbor he found but little shoaling, and found a large deepening in the broad areas lying down stream from Anchorage Shoal, which is not far from a line joining the Simpson dry dock with the most southerly of the walls on the Commonwealth's South Boston flats.

The two sources relied upon in the Harbor Commissioners' report of 1895 for exhibiting this shoaling were the Boschke survey of 1861 and the United States Coast Survey Soundings of 1892, under Lieut. W. F. Low. Translating Mr. Hodgdon's estimates given in cubic yards on p. 4 of that report, into *change of depth in feet*, I find that from the mouth of Chelsea Creek and Mystic River to the line joining the point of the Navy Yard and the Atlantic Works, on an area of about 130 acres, the apparent shoaling averages 1.4 feet, while on the area of about 26 acres, between the lowest Charlestown bridge and a line joining the Boston slip of the Chelsea Ferry and the point of the Navy Yard, the apparent shoaling averages 2.7 feet; but on the larger area of the main upper harbor, comprising the 156 acres between the Navy Yard and Anchorage Shoal, the average shoaling shown during this period was only 0.8 foot.

On the other hand, on the much larger area of 1,130 acres lying between the Anchorage Shoal and Castle Island, a comparison of these

maps of 1861 and 1892 indicates an average deepening of 0.3 foot during this period; and the net result in difference of depths shown by these two maps when averaged for the entire area of 1,500 acres, gives an average deepening of only about $\frac{1}{4}$ inch.

On comparing the soundings of 1835 with those of 1861, still other differences are found, but very curiously many of the areas that apparently shoaled between 1861 and 1892 appear to have deepened between the years 1835 and 1861. Curiously, the map of 1835 appears to present the most complete and precise survey of the upper harbor that has ever yet been made. I have taken pains also to inspect copies of the complete sheets of the surveys of 1861 and 1902, and on each the soundings average scarcely 100 feet apart, and the depths on cross ranges agree so well that the discrepancies between one map and another are hard to explain.

As is stated later, there is some small uncertainty about the real elevation of the datum plane to which these soundings are referred, and a strong probability that the whole bed of the harbor is slowly lowering, from geological causes, at the rate of about an inch in 8 or 10 years, or about one foot in 100 years; but the main reason for the discrepancy between the ancient and modern soundings within the main harbor appears to be the lack of precision in the measurements. On the Boschke map many depths are figured to fractions of a foot from the tide reduction where I find original notes show the record taken in fathoms and whole feet.

The reasons why shoaling of the harbor may not be expected to follow a lessening of the tidal flow, that were advanced by Mr. F. P. Stearns, on pp. 20, 21 of the report of the Joint Board of 1894, and in his evidence before the Harbor Commissioners, appear to be fully sustained by our additional information: —

(*a*) That the currents are already too feeble to produce scour or to prevent shoaling.

(*b*) That there is no adequate source of material to produce shoals in the inner harbor.

The results of our recent investigations may be summarized as follows: —

(1) Notwithstanding that the area of tidal water about Boston inner harbor has been reduced during the past century by an amount very much greater than the present area of the Charles estuary, and that a volume has been cut off from the tidal prism of the Charles, by the filling in of the Back Bay lands and the Cambridge embankments, about as large as that which it is now proposed to cut off, no noteworthy shoaling of the harbor has followed.

(2) Good reasons appear for believing that the apparent shoaling indicated by a comparison of the old surveys with the latest surveys was mainly due to lack of precision of one or another of the soundings compared, and perhaps in small

part due to discrepancies in the elevation of the bench marks to which these soundings were referred.

(3) The small depth of the deposit of silt now found on top of the hard blue clay which formed the original bed of the harbor, so far as yet investigated, proves, irrespective of all soundings and surveys, that there has been no important shoaling of the harbor.

(4) The Board of Commissioners on Boston Harbor, of forty years ago, made surveys and current measurements, which, although good according to the standards of those days, are incomplete and imperfect when judged by the standards of to-day, and their theories were necessarily formulated in ignorance of the geological principles that have been learned in more recent years; and, while at that time it was natural to attribute the formation of the harbor channels to tidal scour, the recent researches of geologists have shown other far more probable causes for a case like this, and it now appears certain that Boston harbor is mainly a submerged valley, eroded many thousands of years ago, soon after the glacial times, when the rivers were larger than now and the land higher than now relatively to the sea, and that this valley was afterwards partially submerged by a slow subsidence of this whole Massachusetts coastal region, which subsidence is probably still in progress.

These matters of the geological history of the harbor are thoroughly discussed in Appendix No. 7.

(5) The velocities of the harbor currents at and near the bottom are found by our recent measurements to be too slow to produce scour and too slow to prevent the deposition of any sand or silt that might be suspended in the water; therefore, a further lessening of these currents can work no harm.

These bottom velocities found now in Boston harbor are smaller than those under which certain deposits of fine sand take place in the Lawrence canal, and much smaller than those found necessary for producing scour. In other words, silt would now be continually deposited in Boston harbor, and the deposit would have been going on steadily for many years past, if there had been any considerable quantity of silt in the water.

(6) The assumptions of the Board of Harbor Commissioners, forty years ago, concerning the velocities necessary to produce scour, were very erroneous, and were based largely on some imperfect experiments made by the French engineer, Dubuat, more than a hundred years ago, which data has unfortunately long posed as authority in sundry

text books, without having been traced back to its original source, as is now briefly done by Mr. Hiram F. Mills, in Appendix No. 9.

(7) The enlarged channels of the Boston harbor of to-day, and of the future, are, and must be, essentially artificial channels, created and maintained by the dredging machine; and by this very enlargement they would be taken beyond the power of the natural tidal scour to preserve them, supposing this tidal scour to have been their cause. This matter is made plain in Appendix No. 8.

XVIII. *Effect of Dam on Navigation and Commerce in Charles River Basin, Cambridge Canals and Upper Harbor.*

This has already been briefly discussed on pp. 64, 65, and the opinion expressed that the gain from a constant level at grade 8, with freedom to move vessels in and out at all times, would more than offset any loss caused by the future height being less than that which is now obtained at the peak of the tide.

The folding diagram showing the present tidal fluctuations, inserted at p. 68, presents the main features of the change in level which affect navigation so plainly that little discussion of this is needed, and an inspection of the photographs opposite p. 67 indicates how great the improvement arising from constant level will be.

It is proposed that the level of the future basin should be at least grade 8, Boston base, and it is proposed to raise this permanently as nearly to grade 9 as future observations upon ground water and the improvement of the margins shall show to be feasible.

There are now periods of neap tide when for nearly a week at a time the basin level rises but little if any higher than it will constantly be after the proposed dam is built; and with the dredging and deepening of canal provided for in the estimate of cost, and with the recent change in design of lock by which a depth of 18 feet below mean low water is to be secured, boats larger than have ever yet been occupied in the commerce along the present wharves around this basin can enter at any hour and proceed directly to their berths, and have far greater facilities and safety than they have ever yet enjoyed.

For filling the lock, passages of such ample size have been designed that it need not take more than eight or ten minutes to fill or empty it under extreme conditions of low water, and it will take much less time than this when the harbor is at above half tide. Winch heads worked by electric motors could aid in the quick entrance or exit of the boat. The main lock gates can be moved very rapidly, and the conditions are particularly favorable for making this one of the most rapid-working locks that can anywhere be found. Its location permits the combination of its power plant and operating crew with that which will be necessary for the operation of a drawbridge.

The one interference with navigation that may be strongly urged is the long period which ice will endure on this body of quiet, fresh water, in comparison with the endurance of ice on the present fluctuating, salt-water basin.

It must not be forgotten that the navigation of the basin is now sometimes closed for more than a week at a time because of ice. The statement presented in the evidence that vessels now enter the basin every month in the year may give a wrong impression to one who has not been familiar with this basin for years.

It appears feasible to keep channels broken through the ice in the future basin by means of a tug boat of special design, maintained as a part of the necessary outfit of the basin, through which channel the wharves can be made nearly as free to navigation as heretofore; and in the design now presented, provision has been made for running out a greater or less amount of the broken ice into the tidal water, by means similar to those used on some of the large water power canals in New England which are maintained open and free from ice throughout the year.

The estimate in evidence of 1902, p. 409, that the change from salt to fresh water would cause a vessel to sink 5 inches deeper, is based upon slightly erroneous data, for it assumes the basin is now filled with sea water at a specific gravity of 1.028, whereas the present basin contains, in the region frequented by navigation, about 10 per cent. of fresh water, thus making the loss of depth of flotation 10 per cent. less, or in all about 0.38 foot for a vessel of 15 feet draught. This objection can be easily met by the amount of dredging provided for and by the deeper lock.

XIX. *Storm Flood Levels in Proposed Basin.*

This matter was carefully investigated by the engineers of the Joint Board of 1894. On p. 16 of their engineers' report it is stated that: "Taking 6,000 cubic feet per second as the amount of water which would flow into the basin in a freshet as great as any of which there are records, and assuming at the same time successive tides considerably higher than the average, careful estimates show that the water in the basin can be prevented from rising more than 2 feet above the normal level." Two feet above their proposed level of 8 is grade 10, Boston base.

The above estimate assumed a flood of larger volume than the great "Stony Brook flood" of 1886, the most severe on record: the basin considered was somewhat smaller than now proposed, because of the dam being about 600 feet farther up stream; it was then proposed to use the lock in emergencies as a sluiceway; and the flood sluices then proposed in the dam were of 300 square feet area, whereas they are now proposed to be of 500 square feet area, with about 400

square feet additional area available for storm flow through the marginal conduits, spillways, ice runs and lock-filling gates, exclusive of the lockway itself. Additional sluiceway would not be expensive.

The present proposition to raise the basin level to grade 8.5 or 9, or as high as ground-water observations made after dam is built shall show to be feasible, will not necessarily raise the flood level at all, for the two features which mainly control the flood level are: —

(*a*) The volume of upland water arriving during the time while the sea tide is above the basin level; and

(*b*) The ability to draw the basin down 1, 2 or 3 feet on the preceding low tide.

There will remain the same opportunity to do this that was contemplated in the plan for constant level at grade 8.

Professor Porter, in preparing his estimates (evidence, p. 405), assumed the flood volume of upland water at 7,000 cubic feet per second, and also assumed that the larger openings and sluices proposed by Mr. Blake would be available and the lock also open; and he assumed the extreme high tide of Dec. 5, 1898, in which, under influence of strong easterly winds, the flood tide reached grade 12.2 and the ebb was held up to grade 3.8, to illustrate extreme conditions, which might some time retard the outflow from the sluices. Under these adverse tidal conditions, with a great freshet, but with a vast amount of sluiceway, he found the basin might become filled to grade 9, and, assuming the still more severe tidal conditions of Nov. 28, 1898, the storm in which the steamer "Portland" was lost, perhaps the most severe wind storm in the past half-century in its effect on tides, with the easterly wind holding the ebb tide up so it did not fall below grade 5.4, he computed that the basin level might rise to about grade 10.4.

The storage area in the basin was assumed by Professor Porter at 33.4 million cubic feet per foot in height; whereas it now, with dam at Craigie bridge, averages 34.4, or 3 per cent. larger, between the contours of 5 and 9.

This computation of Professor Porter's is not applicable to the dam as now proposed, because no tidal sluiceways are now proposed, but is interesting, as showing that, under those extreme assumptions of a freshet greater in volume than any ever yet known coincident with tides of an extreme height at low water that has never yet been observed as coincident with a great freshet, he found the extreme limit 10.4 feet, or slightly lower than the mean level of the marshes and slightly lower than the level now reached by the average daily tide in the upper Charles.

It is now proposed to omit the large tidal sluices, and to make a deeper lock; and it is not certain that it will be thought best to provide gearing sufficiently strong to pull the up-stream lock gate open or close it under pressure, therefore it will be proper to omit the lockway from the areas available for drawing the pond down in preparation

for freshet storage during the succeeding high-water interval. Therefore, we will for the moment accept the extremely improbable coincident condition of extreme freshet and extreme tide, and apply it to the sluiceway areas shown in the drawings on which the present estimates are based.

The four large sluices and the two small sluices beside them present a net area of 500 square feet, for which, from experiments on canal headgates at Lawrence, Mass., and Manchester, N. H., we will call the coefficient of discharge at least 80 per cent. The full discharge of the spillways and ice runs on Boston and Cambridge end is allowed for, because, during the time that the basin is above the level of their crests and the harbor tide below it, these spillways and the marginal conduits are assumed to be discharging at their full capacity. The emergency gates for filling the locks could be included, but their discharge is relatively small. The main lock gates are assumed closed.

Although the greatest flood ever known on the Charles, of which record or tradition remains, was that of February, 1886, when (see Appendix No. 16) the flow at Waltham was probably not over 4,000 cubic feet per second, and the main flood from Stony Brook and the lower tributaries had spent itself and passed before the greatest height over the Waltham dam had been attained, we will follow the prudent suggestion of the late James B. Francis, and assume a flood of much greater volume, such as might come if a rain like that of October, 1869, should fall on frozen impervious ground, and assume a flow of 7,000 cubic feet per second. It is absolutely certain that the main freshet from the Charles would not arrive until a day or two after the main flood from Stony Brook has passed, and that there would thus be ample warning and opportunity to draw the basin down 1 or 2 feet to receive it.

There are two quite different tidal conditions which may be conceived of as lessening the discharge of flood water through the sluices: —

(*a*) Extremely high flood tide caused at a period of spring tides by strong and prolonged easterly winds, thus increasing the length of time during which the freshet water must be stored because of harbor being above basin level, and with the low-water level of the spring ebb held up in about equal measure by the wind, thus impeding the outflow from the sluices, but less than under some other conditions, because the effect of the easterly wind in piling up the water is counteracted by the spring tide tendency to fall low.

(*b*) An extremely high ebb tide at the neap tide period,

induced by a strong and prolonged easterly wind, which would pile up on top of an ebb already high from neap tide conditions.

Our computations show that, with all these unfavorable conditions of extreme tide and extreme freshet coming together,* *which probably would not happen once in a hundred years, and with the basin not drawn below grade 8* during the preceding ebb because of the opposing height of 5.4 feet on the harbor side while it rose in the harbor to 14.6 on the flood,† *the extreme height reached would be 11.8 feet above Boston base, which is 2.8 feet less than the height in the harbor at the same time*, and a less height than the tide in the Charles now reaches in almost every month; and, even if it did reach this height, and some of the park lands became flooded with fresh water for three or four hours, no particular harm would be done.

I consider that fears of trouble from failure of ability to control the flood level of the basin in great storms are groundless.

XX. *Cost of Dam and Lock.*

These questions of cost are answered in detail in Appendix No. 19.

The complete dam and lock, combined with a roadway and drawbridge, with all needful accessory structures, all of the best material and workmanship, can be built for anywhere from $1,000,000 to $1,600,000, according to the elaborateness of detail and the width and height of roadway, and the dam in combination with a bridge will cost just about the same as the bridge alone, of the same width and height, which must inevitably soon be built to replace the present old, worn and decayed Craigie bridge.

I consider that the design called No. 5 (see Appendix No. 19), the high dam 130 feet wide, of solid filling between massive granite walls, with the deep lock having its entrance sill at 18 feet below mean low water, shown in section and in elevation, but without the catch-basins, is well adapted to meet the conditions, and for this I estimate the cost at $1,425,000.

Since this will serve for a bridge, and cost no more than

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* We have in Appendix No. 18 compiled such records as can be obtained relative to extreme tides, and to the conditions of rainfall and flood at the same time. The continuous tidal records at the Navy Yard were kept only from 1847 to 1876, and again in 1902 and 1903. These can be supplemented by the year's observations at India wharf by Baldwin in 1867 and by the records of the Deer Island sewer station in recent years. It is interesting to note that there is no record of any remarkably high tide at the time of the Stony Brook flood.

† These are the heights reached in the great storm of November, 1898, in which the steamer "Portland" was lost.

the necessary new bridge, it would appear fair to divide its cost between the adjacent cities, just as the cost of the new bridge would be divided.

XXI. *Cost of Marginal Conduits.*

The marginal conduit required on the Boston side to intercept the sewage overflow, street wash and polluted Stony Brook discharge, and for providing circulation in the Fens basin (see Appendix No. 19), is estimated to cost $500,000.

The marginal conduit on the Cambridge side for intercepting sewage overflow and street wash from the large Binney Street district, and for providing circulation in the Cambridge canal, is estimated to cost $88,000.

XXII. *Cost of making Good any Injury to Navigation.*

The cost of making good the injury to navigation interests along the Cambridge canals is fully discussed in Appendix No. 12, also briefly in Appendix No. 19, also in argument of Albert E. Pillsbury, Esq., on p. 459 of evidence.

It does not appear reasonable that the State should dredge these private canals to give a depth several feet greater than ever before enjoyed, and rebuild all of the present old and shaky walls, or that contract obligations should be incurred to give greater freedom from ice in the future than has ever been secured in the past, all of which might be called for under the stipulation proposed by the petitioners, and which might cost, as estimated by the chief engineer of the Massachusetts Harbor Commission, nearly half a million dollars (see p. 427).

It appears that a fair and liberal allowance for making the owners fully as well off as they are to-day, and in fact much better off, will be $100,000. The cost of additional dredging in the main basin for navigation and for removal of the three sludge banks is discussed in Appendix No. 19, and I have estimated this at $25,000.

The channels can be greatly improved, simply and cheaply, by the use of discretion in dredging the large quantities of filling required for the dam and for the new esplanade on the Boston side in the rear of Beacon Street, the cost of which dredging is covered in the separate estimates for the cost of these structures, and it is this which favors so small an estimate as that just given.

XXIII. *Cost of dredging Foul Sludge Banks.*

The dredging of the sludge bank in the Fens appears to be purely a city of Boston affair, necessary for sanitation without reference to the dam. There is probably somewhere from 50,000 to 70,000 cubic yards of this material. Although it is stated that dredging of somewhere between 15,000 and 30,000 cubic yards from this basin in 1898 cost $25,000, this is not a fair criterion for an estimate of cost per cubic yard, because of a large part of this expenditure having been absorbed in getting the dredge into position and taking it away. By deferring this dredging until the dam and marginal conduit are built, and an open entrance provided into the Fens basin, the cost can probably be reduced, and it now appears that total cost should not exceed, say, roughly, $40,000.

XXIV. *Cost of Shore Line Improvements.*

The cost of shore line improvements is discussed in some detail in Appendix No. 19, and other interesting data are found on p. 31 of the report of the Joint Board of 1894; and it is easy to understand that, with the basin at constant level, a much cheaper type of wall will serve for extending the proposed marginal improvements up river than will be required under the present conditions with a 14-foot tidal range.

Finally,

It appears that the advantages of the dam and the basin at nearly constant level largely overbalance the possible disadvantages; that sanitary conditions will be improved, and danger of malaria not increased; that interests of navigation and manufacturing will be bettered; that the harbor will not be shoaled by loss of tidal currents; that a magnificent opportunity for wholesome recreation and the enjoyment of a more beautiful landscape will be made possible by the construction of this dam.

As a result of careful estimates, the remarkable fact appears that *this great public improvement, with dam, lock, marginal conduit, esplanade and new embankment walls, and all necessary appurtenances attendant on the substitution of a clean, sanitary and beautiful fresh-water lake, into which large ships can enter and proceed to their berths at any hour, for a foul tidal estuary, need cost not a dollar more than to continue the highway improvements, marginal improvements, sewer and sanitary improvements to which*

Flats exposed at Outlet of Hereford Street Sewer, July 11, 1902. Low Tide at Grade 0, Boston Base.

Beach in Natural Condition below Arsenal Street Bridge   Low Tide, Dec. 18, 1902.

the cities of Boston and Cambridge and the metropolitan district are already definitely committed under tidal conditions without gaining the advantages above named. It will, however, call for an earlier expenditure.

In other words, the dam complete, with roadway, bridge, lock and sluices, costs little, if any, more than the bridge that must necessarily soon be built in place of the old Craigie bridge; and the marginal conduits and their accessories, necessary to the purification of the basin, will be fully met by the lessened cost of improving the present dirty margins of the upper basin, and a moderate dredging of the mud flats exposed at low tide, improving the present unsanitary marshes, and deferring the building of certain new sewers and storm drains already begun in Cambridge.

Respectfully submitted,

JOHN R. FREEMAN,

Engineer.

Appendix No. 1.

MALARIA.

CONCERNING THE PROBABLE EFFECT OF THE PROPOSED FRESH-WATER BASIN UPON THE OCCURRENCE OF MALARIA IN THE TERRITORY ADJOINING THE BASIN.

RESULTS OF INSPECTION OF TERRITORY AND OTHER STUDIES.

By Theobald Smith, A.M., M.D., *Professor of Comparative Pathology in the Harvard Medical School.*

Boston, Oct. 20, 1902.

Dr. Henry S. Pritchett, *Chairman Committee on Charles River Dam.*

Dear Sir: — In response to your request I herewith transmit a brief report upon the probable influence of the proposed fresh-water basin of the Charles River upon the incidence of malaria in the surrounding territory. A brief bacteriological survey of the water within the limits of the proposed basin is also given, in accordance with the wishes of your committee. In this work, which has covered the entire summer, I have been ably assisted in its various details by Charles H. Boxmeyer, A.B.

Very respectfully,

THEOBALD SMITH.

I. — The Bearing of the Proposed Charles River Basin upon the Public Health, with Special Reference to Malaria.

Among the sanitary problems which have been discussed by those interested in the project of a fresh-water basin, the only one deserving extended consideration is the probable influence of the changed conditions upon the incidence of malaria in the immediate environment of the basin.

Since the former hearing upon this same subject in 1894, the situation concerning our knowledge of those causes which favor malaria has been materially improved. At that time, only cautious statements of a more or less vague character were permissible. According to the views current and authorized at that time, malaria was in some way connected

with fluctuating water levels. The periodic exposure of submerged land to air and sunshine was regarded as the chief breeder of malaria. It was also assumed that the turning over of the soil during excavations favored malaria by setting free in some mysterious manner malaria germs whose habitat was supposed to be the soil.

At present it is quite firmly established that the micro-organism of malaria, which produces the well-known disturbances in the body by multiplying in the red blood corpuscles, is transferred from the blood of one individual to that of another by certain species of mosquitoes. This transfer is not a mechanical process, but one accompanied by complex transformations of the parasite in the body of the mosquito, leading to the production of spores. These spores (or, more accurately, sporozoites) are injected into the body of the attacked individual from the salivary glands of the mosquito, when the mosquito has pierced the skin and reached a blood vessel. The development of the parasite in the body of the mosquito to the formation of the sporozoites requires at least ten days, and varies with the temperature, being entirely inhibited by a low temperature. The transmission of malaria is thus a complex biological process of high adaptation. *The malarial microbe is a true parasite in all its stages. It never exists free in the air or in the water, or on vegetation, but spends its life partly in the blood of man, partly in the organs of the mosquito.*

This much it has seemed desirable to state in order to make clear what follows, and also because the minutes of the hearing have not thus far embodied a simple statement of the facts known to-day.

A little reflection will show us that there are three conditions, or associated causes, upon which the incidence of malaria depends. They are: —

1. The species of mosquito;

2. Local conditions which favor or interfere with the breeding of mosquitoes; and

3. The presence of infected human beings, or carriers of the malaria parasite.

The absence of any one of these conditions would make the appearance of malaria impossible. Without the mosquito, no transfer of blood parasites from man to man could take place; without breeding grounds, mosquitoes could not appear; and, lastly, without the infected human being, the disease could not be transmitted, because it is generally held (and there is strong support for it) that the mosquito is not itself infected until it draws blood from an infected individual.

We shall now endeavor to discuss more in detail these conditions, and then apply them to the proposed Charles River basin.

1. Among mosquitoes, the genus *Anopheles* is regarded as the only carrier of malarial parasites. In this genus there are two quite distinct species which are encountered in eastern Massachusetts, namely, *Anopheles maculipennis* and *Anopheles punctipennis*. This genus is not a recent arrival in this neighborhood, for larvæ belonging to one of these species were found by Dr. C. S. Minot ("Journal Boston Society of Medical Sciences," 1901, page 325) over twenty years ago, in ponds in the Forest Hills district. These may be found, together with species of the more common genus (*Culex*) which are generally regarded as harmless, or else alone. We may take it for granted that mosquitoes capable of carrying infection will appear in our midst whenever the conditions for breeding are favorable. I have found them in many parts of the Boston suburbs, and, in fact, in recent years in all places in Massachusetts which I have had occasion to examine on account of past or present malaria.

2. The local conditions for breeding will require a more detailed discussion. Mosquitoes deposit their eggs upon the surface of water. The eggs hatch within one or more days. The young, or larvæ, live in the water for a variable number of days, depending on the genus. They then transform into the so-called pupæ, which, after an additional sojourn of several days in the water, become transformed into winged insects. The mosquito therefore requires water for its evolution into the adult insect. The popular belief that they may develop in moist soil and vegetation is not supported by either observation or inference.

The infecting genus *Anopheles* appears to be somewhat more restricted in its breeding habits than the common genus *Culex*. It is more distinctly a mosquito of rural districts and of water rich in microscopic life. It is found chiefly in fresh water, very rarely in brackish water. The larvæ are in general restricted to small bodies of water. Very sluggish brooks, ditches and pools several feet in diameter (provided the water does not dry out for two or three weeks) are more frequented than larger bodies. This is probably due to the large number of enemies of the young aquatic mosquito, such as various species of fishes and perhaps lower forms of animal life which inhabit or frequent the larger bodies of water. Again, the disturbed condition of the surface of larger bodies of water is inimical to larval life. Hence it may be taken for granted that large bodies of water, such as the proposed basin, will not form a breeding place for mosquitoes, provided the shores are sufficiently inclined and kept free from miscellaneous aquatic vegetation; for mosquito larvæ have been found at times on the margin of larger bodies of water whose banks slope so gradually as to leave but a very thin layer of water, over which a dense vegetation grows, which protects the larvæ. In the latter case the animal enemies of the larvæ can reach them only with difficulty.

The favoring influence of pollution upon mosquitoes in larger bodies of water, such as ponds and rivers, is a matter of considerable importance, although the study of the breeding-places of *Anopheles* is not yet far enough advanced to enable me to make any categorical statement. It has impressed itself upon me, however, from observations made in different localities, that sewage pollution distinctly favors *Anopheles* and also *Culex* in sluggish rivers, either by suppressing the enemies of mosquitoes or increasing the food supply of the latter.* In other words, a body of water which, by reason of its size and other conditions, would be free from mosquito larvæ, might contain them if the pollution was excessive. This is a conservative statement, which may not prove true everywhere, but which I think would hold for the latitude of Massachusetts.

As a rule, however, larger bodies of water, such as rivers, lakes and ponds, may be searched in vain for larvæ. Even in the shallow margins, overgrown with aquatic vegetation, they are rarely found. Their preferred habitat are small pools of stagnant ground water, the stagnant coves of small streams, the ditches of well-manured fields, and all places where obstructions lead to the formation of small, quiet pools in the course of running water.

3. The source of the malaria parasite has been the theme of much speculation among sanitarians. It has been referred to stagnant water, to upturned soil, and to the uncovered banks and bottoms of mill-ponds with fluctuating water levels. With the growth of more definite knowl-

* When mosquito larvæ are found in rivers, impounded by dams or flowing sluggishly, they may have been carried there by tributaries or from coves and other stagnant reaches.

edge in recent years, only two sources remain, — the mosquito and human beings. Of these two, the human being is now quite universally accepted as the source of infection, the mosquito being infected only after drawing blood containing the malaria parasites. In all prognoses, therefore, the population, as regards its density, movements and proximity to breeding-places of mosquitoes, must be regarded as an important factor. The density of population is of importance, as greatly increasing the opportunities for transmission. The movements of the people to and from malarial regions where infection may occur must be considered. Finally, the accessibility of the people to the bites of the mosquitoes, *i.e.*, the proximity of houses to breeding-places, is a determining factor, since the species of *Anopheles* do not seem to move very far from their breeding-places. To the factor of locality must be added the mode of life. Crowding together in the same room, exposure after dark, ineffectual screening of windows, are favoring conditions. The poorer classes thus are more exposed through their habits and domiciles than the well-to-do. It is not safe, however, to depend upon the probable freedom from infection of any community in which the other conditions favor malaria. It appears, from the history of malaria in our own State for the past ten or fifteen years, that, given certain conditions, such as a small but crowded population near breeding-places of mosquitoes, malaria will very likely appear. The occurrence of severe epidemics of malaria in crowded, unscreened labor camps connected with sewerage and water supply works, brick yards and the like, and in the inmates of schools, prisons, etc., shows that nowadays hidden latent infection in some one or more individuals may always be assumed as present, and ready to spread when opportunity is given by proximity to breeding-places of *Anopheles*.*

Hence emphasis must be laid chiefly on the breeding places of *Anopheles*, since the two other factors, *Anopheles* and human infection, may be regarded as present, for our purposes. It should, furthermore, be borne in mind that individuals once infected with the malaria parasite may remain so, with occasional outbreaks of fever known as relapses, which are due to other predisposing causes. Such individuals may form the starting-point of fresh disease in the spring and early summer by infecting the mosquitoes; and it is easy to understand how the increase in the number of infected individuals year by year may make the disease permanent in a given locality.

We may now proceed to apply the facts concerning the incidence of malaria to the proposed Charles River basin; and here the main factor to be considered is the breeding of mosquitoes, as shown above. There are, at the outset, two distinct breeding fields needing separate consideration, the river itself, and the territory surrounding it.

As regards the river itself, we may safely assume that the proposed fresh-water basin will not become a breeding-place for mosquitoes. The basin itself would be very large; it would contain an abundance of fish life; the banks would be so treated as to exclude the possibility that mosquito larvæ might find shelter there. With the removal of the Stony Brook sewage and perhaps other sources of sewage below Harvard bridge, the water would be sufficiently pure, as shown by the bacteriological results herein reported, to support an abundance of forms of fish life. The testimony of these results goes far to show that the

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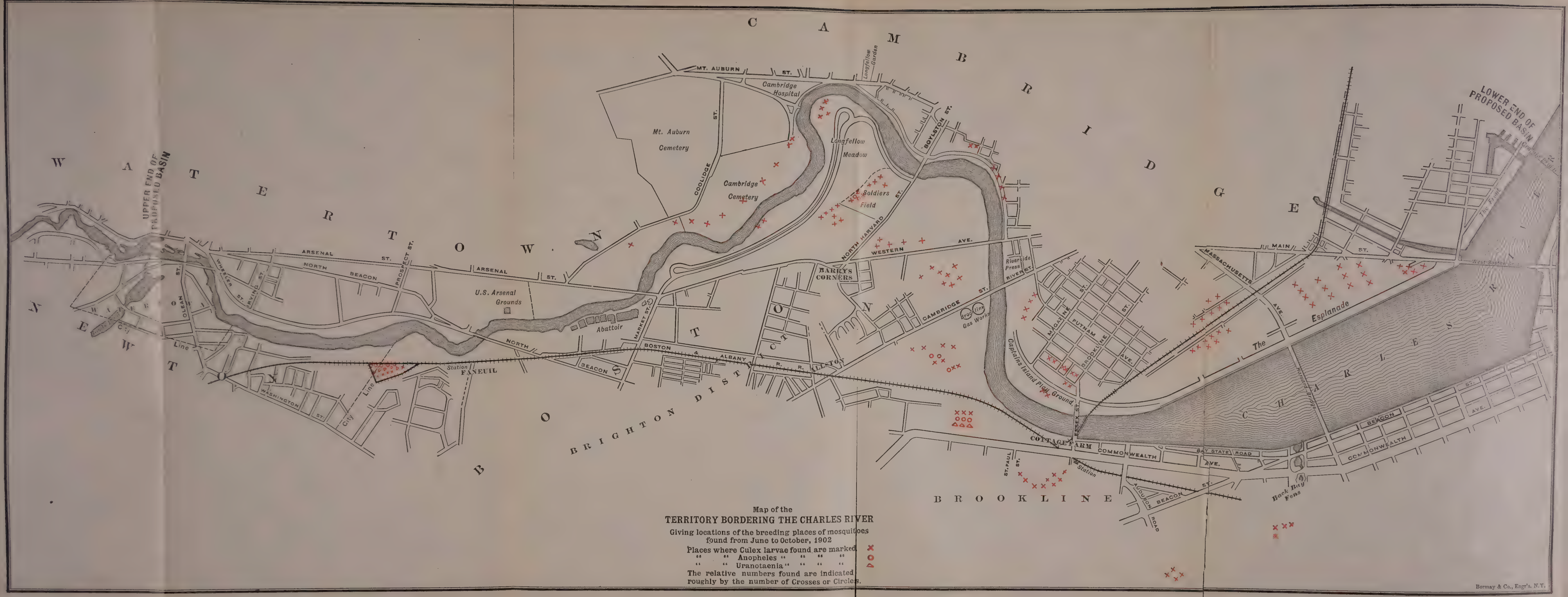
* The case is similar to that of typhoid fever at the present time. Sewage-polluted water may be regarded as likely to produce typhoid when drunk, whether clinical cases of typhoid fever are on the watershed or not; because here also, owing to the masked forms of the disease, and the more or less prolonged persistence of the bacilli in the recovered cases, typhoid bacilli may be present at any time.



Map of the
TERRITORY BORDERING THE CHARLES RIVER
Giving locations of the breeding places of mosquitoes
found from June to October, 1902
Places where Culex larvae found are marked ×
" " Anopheles " " " " ○
" " Uranotaenia " " " " △
The relative numbers found are indicated
roughly by the number of Crosses or Circles.

water would be purer than it is now, owing to the influx of polluted water from the harbor itself at the present time.

The territory bordering upon the proposed basin is of much greater importance with regard to malaria than the river itself; for, if anything should be done which would create breeding-places of *Anopheles* in the environment of the proposed basin, malaria would also be favored thereby. The danger would be two-fold; it would not only menace the fringe of population skirting the breeding-places, but also the people who would frequent the proposed water park, especially after nightfall.

In order to estimate the influence of a change from a fluctuating tidal body of salt water to a body of fresh water with permanent level, it became necessary to examine the territory bordering upon the proposed basin, in order to determine the prevailing conditions favoring the breeding of mosquitoes.

For this purpose the banks of the river were inspected in the latter part of June, again in July, August, and finally in September. The results of the inspection are given in the map of the river. On this map the presence of *Culex* larvæ is indicated with a cross, that of *Anopheles* with a circle.

The breeding grounds may be classified into several distinct categories of differing importance: —

1. Temporary breeding grounds.
2. Collections of formerly brackish and now nearly fresh water, cut off partly or wholly from the tidal areas by roads and railroad embankments.
3. Areas under daily and monthly tidal influences.

The temporary breeding-places are such for two reasons. Those existing in places where refuse is being dumped, and where streets have been graded above the former level of the ground, will disappear in time with the filling up and utilization of the land. Those due to a fluctuating ground-water level, which contain sufficient water to favor breeding during a certain part of the summer season, must be made dry by filling or draining. To the former class belong the depressions on the Cambridge side of the river, on both sides of Massachusetts Avenue, back of the "Esplanade," also a few spots in the Fenway and along the river in Cambridge between Boylston and Cambridge streets. These places are destined to disappear, sooner or later, although for the time being they are as likely to breed *Anopheles* as well as *Culex*, and should be sprayed with oil at intervals.

The second class of temporary breeding-places are so because the water may disappear later in the season, on account of insufficient rainfall and the sinking of the ground-water level. One such place was found on or near the grounds of the Allston Golf Club, not far from the tracks of the Boston & Albany Railroad. This body of water contained both *Anopheles* and *Culex* larvæ in July, but in September the water had disappeared. Similarly, certain small artificial depressions on Longfellow meadow were breeding myriads of *Culex* larvæ in April of this year (1902), but in the summer these pools had disappeared.

Of the second group of breeding-places, comprising certain marsh tracts, more or less completely cut off from tidal influences, there are two deserving attention.

One is a tract situated on the south-east side of Commonwealth Avenue at Cottage Farm and near Essex Street bridge. Here only *Culex* were found, because salt marsh influences still predominate.

The second much more formidable breeding-place is a triangle formed by steep railroad embankments just beyond Faneuil station of the Boston & Albany Railroad. This land-locked marsh was found to contain

Anopheles (in addition to *Culex*) in June, July and September. From the larvæ both *Anopheles maculipennis* and *punctipennis* were bred in the laboratory. This is by far the most prolific and permanent breeding ground in the whole district under discussion. It is essentially created by the railroad, and illustrates a condition so frequently found as a result of railroad construction.

The third group of breeding-places comprises all the marshes under the influence of the tides. This area is quite extensive on the Boston side of the river. It includes the yards of the Boston & Albany Railroad, the territory extending from Cambridge Street to Longfellow meadows and the land through which Western Avenue and Harvard Street pass. On the Cambridge side there is a similar strip along the river from near the Cambridge Hospital to the Watertown Arsenal. In this large territory species of *Culex* have been found breeding through the summer on the outskirts of the marshes, where pools occur which are filled perhaps by the highest tides, but which are not influenced daily. Even these pools, when well stocked with small fishes, were free from larvæ. In two spots of this territory only were *Anopheles* larvæ found, in the Boston & Albany Railroad yards and in an open drain in Soldiers' Field. Those larvæ, which developed into mature insects in the laboratory, were found to be *Anopheles punctipennis*.

Under present conditions, therefore, mosquitoes (chiefly *Culex sollicitans*, — the mosquito of salt marshes) do not breed in those pools, channels or ditches communicating with the river, because daily swept by the tidal currents. Those depressions or pockets filled by the highest tides are usually stocked with fishes and free from larvæ. The breeding takes place chiefly along the edges, where fishes are absent, where perhaps ground water and rain water play some part, and where other still undetermined food conditions are most favorable.

This somewhat detailed survey of the breeding grounds was necessary in order to pave the way for the important question as to what changes these areas would undergo if a fresh water basin of permanent level were to replace the present salt-water body of fluctuating level.

The first and second group of breeding-places would not be affected, excepting the area at Cottage Farm. Here fresh-water conditions would gradually prevail, and *Anopheles* might eventually obtain a foothold, depending on the amount of water.

When we come to consider the third group of breeding-places, — the marshes bordering the river, — the conditions would be materially changed by a fresh-water basin. With more of less quiet water replacing the present tidal currents, all open ditches and depressions might become breeding grounds for *Anopheles* after the salt had been sufficiently removed to favor this genus. The draining of the marshes would have to be done with covered drains, and all channels now used by the tidal currents to carry water to the marshes from the river and back again would have to be either filled, covered, or so treated that fishes would have ready access to all parts of them.

The presence of cases of malaria, or, in other words, of infected individuals, within or near the territory bordering the proposed basin, cannot be accurately ascertained; but information from various sources shows that sporadic cases occur in the Allston and Brighton districts, as well as in Cambridge, during the summer season. There is no evidence of the existence of malaria in a severe or epidemic form in these places; nevertheless, the germ of malaria may be regarded as present in such individuals, ready to spread whenever conditions become favorable.

If we summarize the information at hand, we find that, of the three

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STATE ROAD
VE.
& A. R.R.
ST.
EACON
UDUBON ROAD
AVE.

MAP OF THE FENS BASIN
Showing the breeding places of mosquitoes as they were found from June to October, 1902.
The red line indicates the boundary of the territory explored.
Culex larvae are indicated by crosses ×
Anopheles " " " " circles ○
The relative numbers found are indicated roughly by the number of crosses or circles.
CHARLES RIVER
HARVARD BRIDGE
MUDDY RIVER CONDUIT OUTLET
BEACON ST.
BAY STATE ROAD
COMMONWEALTH AVE.
B.& A.R.R.
BOYLSTON ST.
ESSEX
BEACON ST.
AUDUBON ROAD
BOYLSTON ST.
Boylston Bridge
WESTLAND AVE.
Agassiz Bridge
Stony Brook
BROOKLINE AVE.
HUNTINGTON AVE.
N.Y.N.H.& H.R.R.
B.& A.R.R.

factors concerned in the production of malaria, two may be regarded as always available, — the particular species of mosquito which is common in the rural territory of Greater Boston, and infected human beings. The third factor, the suitable breeding grounds for *Anopheles*, exist only to a very limited extent at present, but might be increased indefinitely by the proposed scheme, if proper treatment of the present breeding-places, and, more particularly, the salt marshes, should be neglected. The feasibility of destroying all the breeding grounds and the expense involved must be passed upon by engineering authorities.

The Fenway.

The Fenway basin, although at present highly polluted with sewage, is also well stocked with fishes, and the banks are in such a condition as to afford no shelter for mosquito larvæ. Here, also, the breeding-places are in the territory bordering the basin, and belong in part to the group of those designated temporary, as they would disappear with the occupation of the land by buildings. In that portion of the Fenway basin just south of Boylston Street bridge the marshy land bordering the water is at present a breeding-place for *Culex*. With the substitution of fresh for salt water this might become a breeding-place for *Anopheles*, unless drained. Here, also, all shallow pools and ditches would become a menace. With a change from salt to fresh water, it is questionable whether the Fens basin itself, under present conditions, would remain free from mosquito larvæ. The high degree of pollution, by interfering with the multiplication of small fresh-water fishes and perhaps by greatly favoring the growth of fresh-water algæ, might eventually lead to the multiplication of *Culex* and *Anopheles* larvæ. This is a possibility, and in assuming it I take the most conservative position upon this question. This necessarily implies the removal of all sewage from the Fens basin, which sewage not only menaces the Fens basin itself, but which shows its deleterious influence in the river, as clearly seen in the bacteriological examinations.

In reviewing all the conditions likely to prevail in the future in and about the proposed Charles River basin, there seem to be none which would tend to favor any increase of malaria, provided the suggestions made are carried out. In fact, the improvement of the banks and the territory beyond them would be a great improvement on present conditions, and tend to relieve those near the marshes of all mosquitoes now breeding in these places, and perhaps remove the causes of malaria prevailing at the present time, unless such malaria is due to bodies of fresh water beyond the immediate confines of the proposed basin.

II. — The Relative Pollution of the Charles River and the Fens Basin as determined by Bacteriological Tests.

Since the relative pollution of any body of water of sluggish movements may modify the influence of other factors which are opposed to malaria, and render them inactive, it was deemed best to make some quantitative bacteriological determinations of the Charles River within the limits of the proposed basin as well as of the Fens basin. The examination made is by no means exhaustive, but I think it furnishes data for estimating the relative pollution, and it incidentally throws some light on the influence of tidal movements on pollution and of the assumed purifying effect of the salt water brought in by the tide from the harbor.

The method adopted was to collect water at a depth of about ten to twelve inches below the surface, unless otherwise indicated; to make duplicate plates with the ordinary nutrient gelatine, and to count the colonies at the end of about forty-eight hours. This method was pursued in all the tests. The samples were plated between one and one and one-half hours after collection. They were kept packed in ice, and the temperature of the sample water had usually fallen to 10° C. at the time of plating. When samples were taken at different depths to compare the relative pollution of the different strata of water, the Esmarch apparatus was employed.

The Fens Basin.

Before discussing the results obtained with samples from the Charles River, it may be well to give the results obtained in the Fens basin.

The stations chosen were Brookline Avenue, the mouth of Stony Brook, the Agassiz and the Boylston Street bridges. The samples were collected with a small boat kindly loaned by the park department, with the exception of the last set, which were taken from the bridges with the Esmarch apparatus. Table No. 1 gives the number of bacteria per c. c.

TABLE No. 1. — *Bacteriological Examination of the Water at Different Points in the Fens Basin.*

DATE.	Time of taking Sample.	State of Tide.	Temperature of Water (Degrees C.).	Bacteria.	STATIONS — 1 Brookline Avenue.	2 Stony Brook.	3 Agassiz Bridge.	4 Boylston Bridge.
1902.								
Aug. 5, ...	10.20-11.01 A.M.,	High water, 12.15 P.M.	21-24	Total bacteria per c. c.,	18,300	182,000	204,400	81,900
				Liquefiers, ...	–	–	–	–
Aug. 8, ...	11.21-11.58 A.M.,	High water, 2.42 P.M.	18-24	Total bacteria per c. c.,	125,700	287,500	395,000	985,600
				Liquefiers, ...	–	–	–	–
Aug. 16, ...	11.35 A.M.-12.17 P.M.,	Low water, 3.15 P.M.	21	Total bacteria per c. c.,	1,400	871,000	28,350	11,650
				Liquefiers, ...	300	–	3,750	2,150
Sept. 25, ...	9.28-10.15 A.M.,	Low water, 11.13 A.M.	–	Total bacteria per c. c.,	50,600	54,400	18,900	20,400
				Liquefiers, ...	5,100	–	1,200	2,750

These figures reveal a high degree of pollution at one station or another, according to the movement of the water, and varying according to rainfall and other undetermined conditions.

They may be profitably compared with a few others obtained from sewage-polluted waters. Thus, in the Illinois & Michigan canal, which, before the opening of the Chicago drainage canal in 1900, received 85 to 90 per cent. of the sewage of Chicago, the number of bacteria per c. c. at Bridgeport, near the pumping station, fluctuated in July and August, 1899, from 445,000 to 1,415,000 (Jordan, "Journal Exper. Medicine," 1900, page 284). The highest figures obtained from the water of the Hudson River in the summer of 1891, just below Albany, after the influx of the total sewage of Albany, Troy and the Mohawk, was 37,366 per c. c. (twelfth annual report New York State Board of Health for 1891, page 536).

The increase in pollution of Stony Brook in passing through the city is roughly indicated by the following figures, which represent tests of the stream at Forest Hills; the water was about six inches in depth, and the samples were taken at a depth of about three inches: —

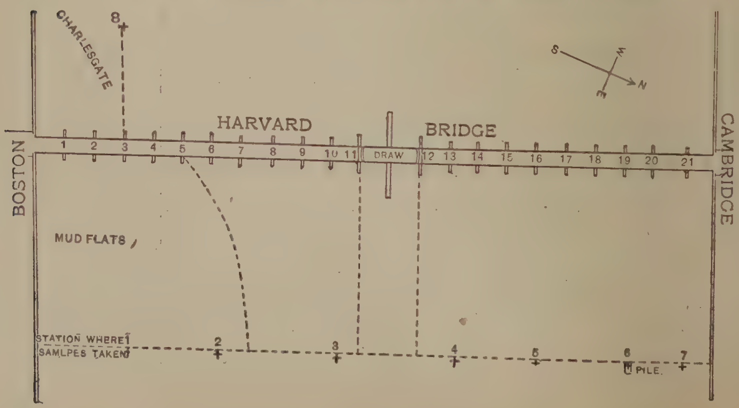
Stony Brook at Forest Hills (Morton Street).

Date.	Time of taking Sample.	Bacteria.	
1902.			
Aug. 20,	1.15 P.M.	Total bacteria per c. c.,	1,600
		Liquefiers,	525
Sept. 16,	12.10 P.M.	Total bacteria per c. c.,	460
		Liquefiers,	65
Sept. 18,	10.10 A.M.	Total bacteria per c. c.,	990
		Liquefiers,	200

The Charles River Basin.

The bacteriological examination was necessarily limited in extent. The samples were collected in such a way as to throw light, if possible, upon three different aspects of the problem: —

1. The difference between water at high and at low tide.
2. The difference between the water in the upper and lower portions of the basin.
3. The difference between the surface and the deeper layers.



For some of the tests a station near Harvard bridge was chosen, as it was assumed that this portion of the river would come under the influence of the Stony Brook sewage. The places where samples were taken simultaneously were in a line parallel with Harvard bridge, and as far below or east of it as the white pile slightly projecting above the water near the Cambridge side. The samples were taken in line with piers 3, 6, 10, 13, 16, 19, 21, counting from the Boston side. The samples were taken both at high and low tide, in order to trace the influence of tidal movements upon the distribution and discharge into the harbor of the polluted Fenway water. In one instance samples at both high and low water were taken on the same day. In Table No. 2 the various data are brought together.

TABLE NO. 2. — *Charles River, near Harvard Bridge (Samples taken about 12 Inches below Surface at Stations in Line with Pile about 500 Feet below Bridge).*

DATE.	Time of taking Sample.	State of Tide.	Temperature of Water (Degrees C.).	Bacteria.	STATIONS — 1 Pier 3.	2 Pier 6.	3 Pier 10.	4 Pier 13.	5 Pier 16.	6 Pier 19.	7 Pier 21.	Remarks.
1902.												
July 28,	9.50-10.12 A.M.	Low water, 10.50 A.M.	18.5-19.0	Total bacteria per c. c.,	6,125	4,300	620	790	460	540	450	Sample taken just before low water.
				Liquefiers, . . .	460	260	50	50	60	50	70	
Aug. 4,	9.36- 9.52 A.M.	High water, 11.25 A.M.	20.5-21.0	Total bacteria per c. c.,	565	1,660	2,110	2,460	9,590	1,370	-	Sample taken one and one-half hours before high water.
				Liquefiers, . . .	45	70	60	95	110	70	-	
Aug. 13,	9.51-10.15 A.M.	Low water, 12.48 P.M.	19.5-20.5	Total bacteria per c. c.,	8,575	1,625	2,525	2,600	3,050	2,300	-	Sample taken two to three hours before low water.
				Liquefiers, . . .	550	100	50	-	50	125	-	
Aug. 20,	12.12-12.21 P.M.	High water, 11.56 A.M.	18.0-19.0	Total bacteria per c. c.,	2,410	2,550	5,450	5,095	5,675	5,550	-	Sample taken just after high water.
				Liquefiers, . . .	60	75	135	130	95	125	-	
Sept. 3,	12.01-12.11 P.M.	High water, 11.55 A.M.	19.5-20.0	Total bacteria per c. c.,	4,775	5,125	3,475	3,625	4,213	4,475	-	Sample taken at high water.
				Liquefiers, . . .	200	225	200	200	200	200	-	
Sept. 22,	8.16- 8.26 A.M.	Low water, 8.20 A.M.	17.5-18.0	Total bacteria per c. c.,	-*	1,887	2,450	2,850	2,275	2,163	-	Sample taken at low water.
				Liquefiers, . . .	-*	250	212	212	225	150	-	
Sept. 22,	2.17- 2.31 P.M.	High water, 2.30 P.M.	17.0-18.0	Total bacteria per c. c.,	1,887	1,725	1,875	(?)925	3,300	1,787	-	Sample taken at high water.
				Liquefiers, . . .	112	112	150	50	175	137	-	

* Exposed flats.

TABLE NO. 3.— *Charles River, above Dam at Watertown (about 50 Feet below Starch Factory).*

Date.	Time of taking Sample.	Temperature of Water (Degrees C.).	Bacteria.	Stations where Samples were taken. Near South Bank.	In Mid-stream.	Near North Bank.
1902.						
Aug. 16,	9.56-10.06 A.M.	23–24.0	Total bacteria per c. c,	850	650	930
			Liquefiers,	365	145	150
Sept. 29,	3- 3.15 P.M.	-	Total bacteria per c. c.,	30,470	14,225	32,500
			Liquefiers,	-	-	-
Oct. 3,	1.40- 1.50 P.M.	20.0	Total bacteria per c. c.,	28,100	36,850	62,475
			Liquefiers,	-	-	-
Oct. 11,	9.40- 9.55 A.M.	15-15.5	Total bacteria per c. c.,	2,500	2,100	2,500
			Liquefiers,	125	125	250

Charles River, near Essex Street Bridge.

Date.	Time of taking Sample.	State of Tide.	Temperature of Water (Degrees C.).	Bacteria.	Stations — 1 75 Feet from Boston Side.	2 At Draw.	3 North of Draw.	4 50 Feet from Cambridge Side.	Remarks.
1902.									
Sept. 4,	12.48-12.53 P.M.	High water, 12.41 P.M.	20.5	Total bacteria per c. c.,	3,800	5,537	5,613	4,662	Sample taken at high tide
				Liquefiers,	175	225	187	150	
Sept. 9,	10.18-10.23 A.M.	Low water, 10.25 A.M.	20.5	Total bacteria per c. c,	575	650	700	675	Sample taken at low tide.
				Liquefiers,	75	25	100	25	

TABLE NO. 4. — *Charles River, just above Charlesgate.*

DATE.	Time of taking Sample.	State of Tide.	Temperature of Water (Degrees C.).	Bacteria.	STATIONS — 1 Pier 3.	2 Pier 6.	3 Pier 10.	4 Pier 13.	5 Pier 16.	6 Pier 19.	7 Pier 21.	Remarks.
1902.												
Aug. 30, .	8.37 8.46 A.M.	High water, 8.22 A.M.	20	Total bacteria per c. c.,	1,225	1,237	1,012	900	1,212	1,122	-	Sample taken at high tide.
				Liquefiers, . . .	225	137	110	75	100	75	-	
Aug. 30, .	2.52-3.21 P.M.	Low water, 2.35 P.M.	21	Total bacteria per c. c.,	-*	362	550	450	425	487	638	Sample taken at low tide.
				Liquefiers, . . .	-*	38	50	50	100	37	63	

* Exposed flats.

Charles River, at Craigie Bridge.

DATE.	Time of taking Sample.	State of Tide.	Temperature of Water (Degrees C.).	Bacteria.	STATIONS — 1 200 Feet from Boston Side.	2 250 Feet from Boston Side.	3 335 Feet from Boston Side.	4 415 Feet from Boston Side.	5 750 Feet from Boston Side.	6 1,155 Feet from Boston Side.	Remarks.
1902.											
Sept. 8,	9.24-9.34 A.M.	Low water, 9.35 A.M.	19-19.5	Total bacteria per c. c.,	2,375	2,600	1,425	2,025	1,400	1,975	Sample taken at low tide.
				Liquefiers, . . .	150	150	100	100	50	125	
Sept. 8,	3.58-4.15 P.M.	High water, 3.46 P.M.	18-20.0	Total bacteria per c. c.,	3,825	3,363	2,475	2,437	1,575	-	Sample taken at high tide.
				Liquefiers, . . .	100	125	-	112	200	-	

To obtain comparative data as to the condition of the surface layer in other parts of the basin, samples were taken above the dam at Watertown, near Essex Street bridge, just above Charlesgate, and just above Craigie bridge. The results are given in tables Nos. 3 and 4.

Two samples were taken in addition to those given in Table No. 4; one, taken at high tide in the inlet near Craigie bridge, on September 17, yielded 10,250 bacteria per c. c.; one, taken in the Broad canal above the bridge, just before low water, on September 22, yielded 4,150 bacteria per c. c.

It might be claimed that the tabulated figures give us information of the surface layer of the river, but not of the deeper portions; that with each inflowing tide a large mass of relatively pure sea water may take the place of the impure water from above. In order to determine the condition of the deeper layers, samples were taken at different depths at Harvard bridge and above Craigie bridge at high and low tide, with the results shown in Table No. 5.

TABLE No. 5. — *Charles River, at Harvard Bridge (showing Relative Pollution of the Deeper Layers; Samples taken in North Channel, at Eastern End of Pier).*

Date.	Time of taking Sample.	State of Tide.	Bacteria.	Depth at which Samples were taken.					Remarks.
				1 Foot.	4 Feet.	8 Feet.	12 Feet.	18 Feet.	
1902.									
Sept. 9, . . .	9.45–9.53 A.M.	Low water, 10.25 A.M.	Total bacteria per c. c.,	462	608	1,637	-	-	Sample taken at low tide.
			Liquefiers, . . .	25	50	75	-	-	
Sept. 11, . . .	7.57–8.18 A.M.	High water, 8.01 A.M.	Total bacteria per c. c.,	1,337	1,762	2,875	2,837	2,688	Sample taken at high tide.
			Liquefiers, . . .	125	113	337	325	250	

Charles River, at Craigie Bridge (in Channel at Draw).

Date.	Time of taking Sample.	State of Tide.	Bacteria.	Depth at which Samples were taken.						Remarks.
				1 Foot.	4 Feet.	8 Feet.	16 Feet.	20 Feet.	25 Feet.	
1902.										
Sept. 17, . .	10.51 11.12 A.M.	High water, 10.45 A.M.	Total bacteria per c. c.,	(?)825	2,350	3,487	4,137	-	3,925	Sample taken at high tide.
			Liquefiers, . . .	-	-	-	-	-	-	
Sept. 23, . .	9.13– 9.36 A.M.	Low water, 9.11 A.M.	Total bacteria per c. c.,	2,063	3,000	3,212	3,325	3,675	-	Sample taken at low tide.
			Liquefiers, . . .	-	-	-	-	-	-	

Interpretation of the Bacteriological Results.

A closer examination of the results obtained near Harvard bridge indicates that there are currents or zones of differing degrees of pollution, as might have been anticipated. In general, the Boston side is more polluted during low water, due to the discharge of water from the Fenway. With the returning tide, the deeper water in the channel is at times most polluted. Taking the surface layer as a whole, there is nothing to indicate that it is purer at high tide than at low tide; in fact, an average of the samples taken simultaneously across the river indicates, that, if anything, the incoming water is somewhat more polluted, as is indicated in the following table, in which the samples of the outgoing and of the incoming tide are averaged and placed in two groups: —

Harvard Bridge.

DATE.	State of Tide.	Number of Samples averaged.	Average Number of Bacteria per c. c.
1902.			
July 28, . .	Tide nearly out.	7	1,902
Aug. 13, . .	Two and one-half to three hours before low water.	6	3,445
Sept. 22, . .	Low water.	5	2,325
Aug. 4, . .	One and one-half hours before high water.	6	2,932
Aug. 20, . .	Just after high water.	6	4,455
Sept. 3, . .	At high tide.		4,281
Sept. 22, . .	At high tide.		2,114

The double test, on September 22, at both high and low tide, indicates a result slightly in favor of the incoming water; but, unfortunately, the figures for one of the stations (4, Table No. 2) were so low, as compared with the stations on either side, that some error must be assumed, and the figures of that particular sample were, therefore, thrown out. Taking the figures as a whole, we find nothing to suggest a better condition of the surface at high than at low water.

The results obtained at Essex Street bridge show a very great difference in favor of the outgoing tide. Those at Craigie bridge, taken on the same day, at both high and low water, although still in favor of the outgoing tide, indicate a greater uniformity, resulting, probably, from the mixing effect of the to-and-fro movement of the water.

The results obtained just above the dam at Watertown are anomalous, in that a relatively low bacterial count was obtained August 16 and a very high count September 29. It was thought at the time that some error had been made, and another set of samples was obtained on October 3. The count, however, proved even higher.

On October 11 the number of bacteria had fallen from an average of 40,000 per c. c. (on October 3) to 2,400. A careful scrutiny of the plates showed that the larger number of the bacteria belonged to one species not known to be directly associated with sewage. The cause for this sudden rise in the number of bacteria is not known. It may have been due to the rains preceding the dates of collection, which are apt to stir up sediment rich in water bacteria in shallow rivers and their

tributaries. A similar occurrence is regularly observed in the Potomac River after rains. The number of bacteria rises in proportion to the clouding of the water with finely suspended particles of earth.

It is also possible that some artificial disturbance occurred which flooded the river with bacteria from the deposits in the bottom. An examination of the upper Charles near West Roxbury (Spring Street) on October 7 gave the following result: —

DATE.	Time of taking Sample.	Bacteria.	STATIONS WHERE SAMPLES WERE TAKEN.	
			Near West Bank.	Near East Bank.
1902.				
Oct. 7, . .	11.10–11.13 A.M.	Total bacteria per c. c.,	587	712
		Liquefiers, . . .	100	100

This indicated that the disturbance, whether due to rain, to changes of the water level controlled by dams, or to factory waste, was located below this point.

The possible influence of some factory waste was tested as regards the starch factory below which the samples had been taken. On October 11 the average number of bacteria below this factory was 2,400; 200 feet above the factory, 2,700. This, therefore, could not have been the temporary cause.

That the bacterial count of the fresh water coming from the upper river was fairly low during the summer is made probable by the low bacterial counts found at the Essex Street bridge, and above Charlesgate, at low tide. (See tables.)

On the whole, I cannot attribute to this temporary rise of bacteria in the river above Watertown any special significance. It is known to occur after rains in all rivers like the Charles, and the uniformity of the bacteria species does not point to a sudden influx of sewage or similar filth.*

When we come to the bacteriological results obtained at different depths, the illusion that a great body of pure salt water is injected into the Charles River, which is assumed to remain below the surface, is completely dispelled, for we find here a steady increase in the number of bacteria from the surface down, both at Harvard and at Craigie bridge. Giving the greatest latitude to our interpretation on account of possible sources of error, we still have undisputed evidence that the tidal portion of the Charles River is, to a certain degree, a settling basin for bacteria, and that the incoming water furnishes a large, though undetermined percentage.

The foregoing discussion of probable future conditions is based entirely on the assumption that the basin proposed would be a body of

* After the foregoing report had been written, I was informed through Mr. Freeman, engineer to the committee, that some work had been going on which most likely was at least one of the causes of the high bacterial count. The other was the rainfall just before the samples were collected. I quote the engineer, distribution department, Metropolitan Water and Sewerage Board, Mr. Dexter Brackett: "The driving of piles for the coffer-dam in Charles River near Norumbega Park was begun on August 15 and was continued until about September 20. On or about October 1 the water was pumped out from the inside of the dam, and the excavation of mud and gravel was in process until October 15." This shows that from August 15 the river was not in a normal condition, but the effect had not reached Watertown when the first samples were taken, on August 16.

fresh water. The introduction of salt water from the harbor has been suggested as a means of periodically cleansing the basin, if it should become objectionable. This periodical washing out would imply the removal of all the fresh water fauna and flora which had established itself, and the introduction of the harbor fauna and flora. If this were done at frequent intervals, the conditions as regards life would remain much as they are now. If the basin were flushed at long intervals, there would be a struggle between fresh water and salt water conditions, and probably the destruction or injury of all life temporarily. If we base ourselves upon broad, general, biological principles, it would seem that, in a basin such as the one under consideration, we should endeavor at the outset to establish such an equilibrium of life as will maintain itself without annoyance or danger to health, and which will tend towards purifying the water without the aid of the salt-water broom, which is destructive while it sweeps out.

The fresh-water basin, properly protected from pollution, would become in time a natural reservoir of animal and vegetable life; while the introduction of salt water would, if frequently done, make an artificial reservoir out of it. It seems to me, therefore, that, while provision should be made for the washing out of the basin, reliance should not be placed upon this palliative method to the exclusion of preventive methods to be inaugurated at the outset.

Conclusions.

1. The substitution of a fresh-water basin for the present tidal reservoir would not tend to intensify malarial influences, provided the present breeding-places of mosquitoes are properly dealt with. There would be material improvement over present conditions, both as regards mosquitoes and malaria.

2. The present pollution of the Charles River is due, in the main, to the sewage poured into the Fens basin by Stony Brook, to the few other sewers below Harvard bridge and to the tidal water from the harbor. The relative pollution brought by the harbor water cannot be estimated without exhaustive investigation. The average number of bacteria of the uppermost layer of water below Essex Street bridge may be estimated roughly at 3,000 — 4,000 bacteria per c. c. With the impounding of the water and the removal of the sources of sewage indicated above, this number should not exceed 1,500 per c. c. and it would probably be less. Water having this relatively low bacterial content could hardly make itself offensive either by suppressing fishes or unduly favoring fresh-water algæ; its bacterial content would, in fact, be but little higher than that of the Charles River above the Watertown dam, under normal conditions, which portion of the river is not offensive.

3. The introduction of salt water from the harbor will probably not be needed, and it should only be reserved as an artificial remedy for extreme, unforeseen conditions.

Appendix No. 2.

Concerning the Pollution of Charles River.

By John R. Freeman, *Chief Engineer.*

Evidence presented to Committee upon Overflows of Sewage into Charles River in Time of Storm.

The experts differed widely in their estimates of the quantity of sewage overflowing into the basin, and those who presented figures made it all the way from 1 per cent. to 7 per cent. of the entire amount of sewage that originates in the sewered water-shed of about 20 square miles tributary to the Charles River within the metropolitan district, which contains a population of about 300,000.

Dr. Henry J. Barnes (p. 292) reported that he had personally observed large quantities of a disgusting form of pollution entering the basin from sewer overflows in time of storm; other experts, some of whom had evidently given much time to this subject, made little or no reference to this occasional concentration of the floating filth.

By certain experts of high standing it is stated that the amount of sewage entering the basin can surely be taken care of, diluted and absorbed by natural forces without offence; while other experts, also of high standing, strongly maintain that these overflows of sewage would surely make the proposed stagnant basin very offensive to sight, smell and health.

Reviewing very briefly the statements of some of the principal experts, we find: —

On page 14 of evidence, in a statement presented by Mr. William Brown, chief engineer of metropolitan sewers, on behalf of H. H. Sprague, chairman of the Metropolitan Water and Sewerage Board, it is said that in Cambridge the aggregate period of overflow is about 7 per cent. of the entire time, and that, after the completion of the new high-level sewer, two years hence, "it may be anticipated that the period during which the south metropolitan sewers will be shut off will not materially vary from that now observed at Cambridge."

Mr. Brown apparently bases this solely on the overflow recorded by the Cambridge sewer clocks as set forth in a record since found incomplete (see also pp. 123–125). He makes no prediction as to the effect of this amount of pollution upon the quality of water in the future basin.

Mr. L. M. Hastings, city engineer of Cambridge, on pp. 47 and 48 of evidence, presents tables showing that the Binney Street regulator gate had been closed and, it might be presumed, forcing sewage out into the Charles, 6.3 per cent. of all the time, during the years 1899, 1900

and 1901, while the tide gate had been open only 2.88 per cent. of the entire time.

I have, with Mr. Hastings's co-operation, since made a very much fuller analysis of these records, and find the average duration of rejection and discharge of sewage into the Charles River for these four years by these same records amounts to 4.8 per cent. of the entire time for the whole year, while only about half of the whole quantity of flowing sewage is rejected during this time that rejection is going on.

Mr. Percy M. Blake, in p. 203 of evidence, presents a diagram compiled from his own examination of the Cambridge sewer overflow records, which gives substantially the same number of hours during which sewage would be thrown out into the Charles River by storm water as the table presented by the city engineer of Cambridge (p. 48); and (p. 204), assuming for the moment that the sewage is proportional to the time, or that the ratio of the volume of sewage rejected to the total volume of sewage produced by this population is the same ratio that the time of rejection bears to the total time, he finds that population required to offensively pollute the basin by this proportion of its total sewage would have to be far in excess of the actual present population and far in excess of the probable future population.

Mr. Blake concludes that the present volume of sewage overflowing could be cared for by existing natural forces without any special salt water sluices or special marginal conduits, and not give offence.

Dr. Henry J. Barnes, professor at the Medical School of Tufts College, located near to the Fens (evidence, pp. 292–302), calls attention very strongly to the present pollution of the Fens basin. He says its bottom is covered with sewage filth, and he calls particular attention to the foul overflows into the Charles from the Hereford Street sewer and the St. Mary's Street sewer in time of storm, and to the great width to which he had observed the basin defiled by sewage overflow.

From reading Dr. Barnes's testimony, it would appear that he did not appreciate the extreme thinness in which the layer of turbid fresh water from these overflows spreads out over the heavier salt water, thus greatly exaggerating the appearance of pollution of the basin, as seen from the bridge.

Mr. J. Herbert Shedd (pp. 361-365 of evidence) makes many figures, and concludes that the pollution would be exceedingly small, and that forty-six times as much pollution as actually will enter could be taken care of by natural forces before the water in the basin would become offensive.

Some of the assumptions on which Mr. Shedd's computations rest are plainly very erroneous, but the margin of safety which he finds is large, and his experience and judgment, apart from his figures, give weight to his evidence. He says: "*I conclude, therefore, that beyond a doubt the sanitary condition of the Charles River, if improved by maintaining a dam as proposed, will be entirely satisfactory.*"

Prof. Dwight Porter (p. 413 of evidence) says, in effect, that the Cambridge automatic records of closing of certain sewer regulator gates and opening of certain tide gates "apparently afford the only direct evidence as to the frequency or duration of sewage overflow into the Charles River," and that for about 7 per cent. of the time the Binney Street regulator rejected the sewage brought it by the Binney Street

sewer, and on p. 418 he (erroneously) assumes that the whole of this sewage for 7 per cent. of the time was necessarily discharged into the Charles River basin; and that this 7 per cent. of overflow occurred in a year in which the total rainfall, the total number of rainy days, and the number of rainy days with more than 0.30 inch of rain, were all less than the average.

Professor Porter further states, in p. 415 of evidence, that the Boston main drainage system is modelled substantially after that of London in the matter of intercepting sewers, with nominal provision for intercepting sewers to receive ¼ inch of rainfall in twenty-four hours in each case; and that the rainfall records of Boston, in comparison with those of London, indicate that it would be fair to expect a materially larger number and a longer total duration of overflows from Boston sewers than from those of London. He says it was estimated that 5 per cent. of the London sewage would escape through the overflows, but it was actually found that overflows were more frequent than anticipated.

Professor Porter concludes that *the condition of the proposed basin would surely become very offensive, and refers to the present condition of the Back Bay Fens basin as an illustration.**

The State Board of Health in a communication signed by its secretary says in conclusion (p. 91): "*The amount of sewage entering through the storm overflows . . . would be so small compared with the flow of water in the river that it could not be regarded as a menace to the health of those boating on the basin or living on its borders.*"

Mr. H. X. Goodnough, chief engineer of the State Board of Health, (p. 104 of evidence, etc.), does not use the Cambridge sewer clock records as his basis for estimating the quantity of sewage pollution, but relies upon the relation of the rate and duration of rainfall to the surplus capacity of the main drainage and metropolitan sewers, and restricts his estimate of quantity that will overflow to those months in which the discharge is likely to prove most offensive.

From a review of the records of rainfall and stream flow, he finds "that the three months of July, August and September, 1900, probably represent the condition of the least dilution of sewage discharged into the basin of any three months within the past twenty-seven years."

From a study of the rainfall records and on the assumption that half the rainfall reaches the sewer during the time within which it falls, and from the known quantity of storm water that the sewers can carry in addition to the ordinary dry-weather flow of sewage, he estimates that during these three months of least dilution the percentage of the total sewage that would have been discharged was about 1.4 per cent.; and (p. 111) that, *after the completion of the high-level sewer has given relief from the present overloading of the Boston main drainage, only 0.7 per cent.*† *of the sewage will overflow in the month of least dilution.*

Mr. Goodnough's investigations plainly led him to conclude that there was no danger of the proposed basin becoming offensive.

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* Our investigations prove Professor Porter's statement, p. 410, that "The Fens basin receives some of the time relatively no more organic matter than the Charles brings over the Watertown dam," is misleading, to say the least.

We find the daily circulation of water in the Fens is less than one-fourth part as great as Professor Porter assumes; the assumption on p. 418, from which he estimates that the equivalent of the constant flow of the sewage of 21,000 persons now enters the basin, is shown unwarranted, particularly that which neglects all account of the flow of the metropolitan sewers during the period of rejection.

† These figures, "1.4 per cent." and "0.7 per cent.," are averages of Mr. Goodnough's figures for the three main districts, made by giving weight in proportion to the population in each.

Mr. Rudolph Hering (evidence, p. 437) says: "The theoretical computations of the amount of filth escaping from the overflows *may be far from giving the true results regarding the expected quality of the water, for they deal with averages. I cannot agree to such a method of computation in this case.*

Although he presents no estimates of his own as to the amount of this pollution, he concludes that *the condition of the proposed Charles River basin would surely be offensive unless overflows of sewage are removed from entering the basin.*

The late Albert F. Noyes, for many years city engineer of Newton, for a time assistant engineer of the Massachusetts State Board of Health, and for whose earnestness, candor and skill in sanitary matters years of personal acquaintance gave me great respect, on p. 831 of evidence of 1894, gave it as his opinion that if the basin were changed to a fresh-water basin it could be kept in a proper sanitary condition, and cited for proof certain ponds in Newton which received considerable quantities of pollution and street wash, and had absorbed this without offence so long as maintained at constant level, although when drawn down so as to expose the bed there had been some trouble.

Mr. F. P. Stearns, now chief engineer of the Metropolitan Water and Sewerage Board (pp. 426–597, evidence, hearings of 1894), presented many statements that should have great weight in the present discussion, because of his exceptional opportunities for observing the effects of sewage pollution while chief engineer of the State Board of Health, and because of his great familiarity with the local conditions and his two years of experience in charge of operating the Boston main drainage.

Mr. Stearns concluded *that no danger whatever was to be apprehended on sanitary grounds; that only about 1 per cent. of the sewage of the water-shed would enter the basin; and that, if objectionable odors should by any chance appear, the basin could be flushed by harbor water temporarily.*

The differences in the foregoing statements and conclusions by experts of high standing, and the most of them exceptionally well acquainted with the territory in question, indicate the difficulties that surround the accurate determination of the quantity and effect of this pollution.

Until the quantity, quality and effect of this pollution is known with certainty, within limits, no intelligent recommendation can be made as to the auxiliary structures needed to prevent a nuisance, and, indeed, the advisability of the proposed dam will remain in doubt.

A close study shows that these differences between the experts arose largely because of assumptions from different points of view, made in the absence of observed and recorded facts; and, *before attempting to critically value and discriminate between the theories already advanced, and before framing new assumptions, it appeared wise to get at all the facts bearing upon this question of pollution that could be found out before the date fixed for report.*

My desire for further study *in the field* was encouraged by observations on a cruise up the basin after an overflow of sewage caused by a thunder shower of 0.35 inches depth, nearly all of which fell within one hour, during which I saw much floating excrement and other evidence of defilement drifting with the tide; and by my personal inspection of the actual condition of foulness of the water of the Fens basin near the Stony Brook outlet, and my inspection of the conditions inside the new Stony Brook conduit and of the brewery waste and house drainage entering its open channel.

I have been profoundly impressed with the importance of making no mistake about unsanitary or offensive conditions in the water of the proposed basin, and the following matters were investigated in the effort to make sure that there should be no under estimate of the pollution: —

SCOPE OF INVESTIGATIONS REGARDING POLLUTION.

I. A careful contour survey of bed of basin was made, so that depths of all shoals, channels and pockets could be known, and so that deposits of mud or sludge could be accurately located; all this having some bearing upon the future plant life and animal life in the basin, and its capacity to dispose of fertilizing material, while this survey was mainly needed as a basis for estimating the cost of dredging the mud flats and for studies of the improvement of navigation. Another object was the opportunity afforded during the progress of this survey to become familiar with and to observe any circumstances affecting the pollution of the basin.

The old maps of soundings were found almost useless, because of the many changes made by dredging and filling in recent years, and these new maps will be worth their cost for their aid in many studies for public works, even if no dam is built.

II. Many thorough inspections of all parts of the basin were made, with the aid of a power boat, under different conditions of sun, storm, wind and tide. Drawtenders and others were questioned about frequency and amount of floating polluting matter observed.

More than 95 per cent. of the water surface was commonly found free from any visible, noteworthy pollution; but during a large part of the time a large quantity of rubbish, fruit skins, waste paper and unsightly material was found driven by the wind into coves or eddys like that near the Union Boat Club. Much dirt and rubbish is at times brought up by the tide from the harbor.

III. Several tours of inspection around margins were made at low tide in heavy rain, in order to observe discharge of the sewer storm overflows, and to observe if there were other sewers, street drains, factory drains or other drains not shown on plans.

It was found that on rare occasions in time of storm large amounts of disgusting filth are flushed out from some of the sewer overflows, and on two occasions certain sewer overflows were found discharging large quantities of undissolved human excrement, leaving long traces of floating filth.

Only a few small unrecorded drains were found, and, while some of these were locally offensive, their total magnitude was not sufficient to materially affect the main problem.

IV. A comparison was made of the turbidity from sewer overflow in time of storm along the Cambridge shore and along the Boston shore, for estimating their relative proportions; also sundry observations on the thinness of the broad stratum of turbid street wash overlying the salt water of basin.

The stratum of turbid fresh water from street wash, etc., was found to be remarkably thin and widely spread out as it floated on top of the

heavier salt water, and thus gave an appearance of pollution all out of proper proportion to its real magnitude. The width of the discolored water down stream from Harvard bridge to Craigie bridge was found, while crossing back and forth in a boat at various points on one of these inspection tours, to be three to five times as wide near the Boston shore as along the Cambridge shore.

V. Many tours of inspection were made throughout the Fens basin, in order to observe the appearance of water, odors, location of filthy deposits and of bubbles of gas arising from putrefaction and to observe any other indications of pollution.

The water of the Fens basin was at all times found foul, and during the warm weather the gaseous products of putrefaction were continually bubbling up from the sludge banks where Stony Brook discharges into the Fens, near Huntington Avenue. In time of rain large quantities of fæces were observed entering the Fens basin from Stony Brook, and some fæces were observed coming in at this point during dry weather, plainly proving that sewage continually enters the new Stony Brook conduit.

VI. A measurement of the actual circulation of new water through the Fens basin was made, and a measurement of the leakage of its defective gates and bulkheads; a self-recording gauge was set to measure the rise and fall of surface of Fens basin.

It was found throughout our observations that the daily rise and fall, due to emptying and refilling with new water, was only about 9 or 10 inches instead of 18 inches, or that the real rise and fall was only half that reported at the hearings (see p. 118), and it was further found that the tide gates designed to produce circulation leak so very badly that 60 per cent. of the salt water admitted at Brookline Avenue for flushing escapes backward through these leaks without ever circulating through the basin.

We made soundings giving the present depth of water in all parts of the Fens basin, and borings were made through the soft sludge to the harder original bottom, in order to determine the depth of the deposit of sludge throughout all parts of the basin, and a map has been prepared showing this. About one-fourth part of the original water volume of this basin is found now filled with foul sludge, or there is now about one-third as much of sludge as there is of water in this basin.

The present quantity of soft polluted sludge in the basin is found to be, after allowing for uncertainty of measurement, upward of 50,000 cubic yards. In other words, this basin probably now contains a quantity of sludge three times as great as the amount reported dredged out in 1898. See evidence, pp. 79 and 114.

VII. Several tours of inspection were made up inside new Stony Brook conduit, two of them through its entire length; and the dry-weather discharge of all sewers and other openings into this was gauged, and samples of its waters at various points were collected for chemical analysis.

This new conduit, "the commissioners' channel," was found in an exceedingly filthy condition, particularly so at from half a mile to a mile below its upper end, almost as foul as a sewer, with many accumulations of rubbish, behind which filth collects and putrefies. Small

but noteworthy quantities of sewage were found entering this channel in dry weather at several points.

VIII. Several tours of inspection were made up along the present open channel of Stony Brook from near Jamaica Plain to above Forest Hills and along Goldsmith Brook to West Roxbury.

Considerable quantities of brewery waste and house drainage were plainly to be seen entering it, and within the mile from Forest Hills down to Jamaica Plain this stream was found in process of transformation from a clean-looking rural brook to a foul-appearing drain.

IX. Several inspections of the open portion of the old Stony Brook channel near its head, a short distance below the factory of the Boston Belting Company.

All flow into the old channel from the territory lying farther up stream is here cut off by the lower grade of the new channel and by a wide embankment within the premises of this factory. No foul water from the Boston Belting Company was found entering, but the Belting Company was found discharging a quantity said to average two million gallons of clear water daily into the brook (water from the metropolitan supply which had merely been passed through its engine condensers); but the dirty bed of the open channel, a short distance below these premises, and its surroundings, showed that polluted surface drainage and street wash entered immediately.

X. A tour of inspection inside old Stony Brook channel, to make sure about its pools of filth, or if sewers enter, was planned, but has been carried out only in part. A deep deposit of sewage sludge was found in the portion inspected.

This channel is reported to be in a very dilapidated and foul condition, and the chemical analysis indicates that it receives sewage continuously.

The chief engineer of the Boston Sewer Division reports that this should be rebuilt as a surface water drain and overflow channel, apart from all considerations of the proposed dam, and estimates its cost at $302,000.

XI. An inspection of the outlet and of the course of each tributary brook within the thickly settled metropolitan district, which brings street wash into basin, or which may bring in other defilement or factory waste, was begun, but this work was interrupted by pressure of other work and by inclement weather.

In general, the factory wastes were apparently fairly well taken care of by diversion into existing sewers; and the many inspections that were made of all these brooks at the point where they enter makes it sure that no serious unnoticed source of pollution exists.

Several privies and other objectionable drains were found discharging into Broad canal.

XII. An inspection of factories, power plants and other gas works and breweries along tributaries of the Charles River basin was made, in order to estimate the quantity of dye stuffs, chemicals, wash water, cylinder oil and similar waste that escapes into the stream.

This work was also interrupted by pressure of other matters. Speaking generally, nothing offensive was found that could not be taken care of at moderate expense, or that seriously complicates the problem of maintaining the cleanliness of the basin. The intercepting sewers are located where drainage from nearly all of these factories can be easily taken into them.

XIII. A careful study was made of the Cambridge sewer clock records, in their relation to rainfalls and height of tide, in great completeness and detail, by means of replotting all of these notes on new diagrams, along with tide curves and rainfall records.

Instead of these showing that about 7 per cent. of the total sewage from the water-shed enters the Charles, as considered by some of the experts whose evidence has already been quoted, it is found they give conclusive proof that not more than about 2 per cent. of the total sewage of these particular districts enters during the six warm months in which such material could give offence.

XIV. As an aid to our estimates of storm flow, the notes of certain very instructive gaugings of sewers, made by the city engineer of Cambridge in 1900, but not heretofore worked up, were very courteously placed in our hands by Mr. Hastings, and, on being worked up, are found to give much light on this problem of sewer overflows.

The duration of the storm flood wave period in small sewer districts was found to be very much shorter than for the large Binney Street and Bath Street districts, and it was found that while in a certain rather steep, semi-urban district with a clay subsoil the run-off of storm water in the sewers amounted to about 40 per cent. of the volume of rainfall in heavy storms, it was smaller in gentle rains; and on a contiguous district, with sandy subsoil and flat grades, the run-off seldom in warm weather exceeded 25 per cent. This smaller per cent. of run-off leads toward a somewhat smaller estimate than heretofore made of the per cent. of sewage rejected from the overflows in the suburban districts in time of storm.

XV. New sewer clock gauges have been set on several representative Boston sewer outlets, and their records studied in comparison with the Binney Street records.

Generally speaking, the overflows of sewage at Hereford Street and St. Mary's Street, Boston, were found agreeing closely with the period of rejection observed at Binney Street, Cambridge, in the same storm; but it was found that under present overloading of outlet the Charles River valley sewer does show a rise under somewhat smaller rainfalls, and continue overflowing longer after a heavy rain.

XVI. A detailed study of the conditions affecting overflow in each individual sewer district tributary to the Charles was made.

It was found that, as a whole, the quantity of sewage overflowing into the Charles in time of storm would in all probability be somewhat more than the proportion shown by the Binney Street clock gauge, and that, after the new high level sewer is put in use (about two years hence, or before the dam could be finished), the total amount of sewage enter-

ing the basin, intermittently, will be equivalent in quantity during the six warm months to the continuous discharge of the sewage of somewhere between 5,000 and 10,000 population.

XVII. Bacteriological tests under the supervision of Dr. Theobald Smith were made in order to obtain a better idea of the present pollution of water in the Charles basin by a study of comparative numbers of bacteria in various representative localities about the basin, in comparison with those found in the fresh water entering basin above Watertown, and in comparison with the number found in representative samples of sewage. These studies by the pathologist have been supplemented by a large number of bacterial counts made under the supervision of the chemist in charge of the water analysis laboratory of the State Board of Health.

The evidence of sewage pollution in the water of the present basin is plain. The tests show that this comes in mainly from Stony Brook. The water of the flood tide at Harvard bridge bears distinct marks of pollution, and, from the pathologist's point of view, is far from possessing the purity of unpolluted sea water.

XVIII. Chemical tests were made, similar in scope to the above. Upward of 650 samples of water have been collected from representative portions of the Charles basin, the Fens basin and their tributaries, and analyzed; and much original research work on the capacity of this water to dispose of pollution without offence has been carried on by the chemist.

So far as chemical tests show, the water of the present basin is fairly clean and contains an abundance of oxygen at all depths. The incoming upland water is found fairly clean, contains an abundance of oxygen and is well adapted to dispose of a considerable amount of pollution without offence. It appears highly probable, that all of the pollution now entering the basin — which is much larger than it will be two years hence, when the high-level sewer is finished — could be absorbed without offence, and without the necessity for marginal conduits to intercept the sewage overflow and street wash.

XIX. Inspection and sampling of mud at bottom of basin, in order to learn more definitely the composition of the deposits of sewage, sludge, silt or putrescible matter.

The percentage of putrescible material was found small, and it is hardly possible and certainly not probable that any of the mud banks, with two or three exceptions, contain organic matter enough to rob the overlying water of its oxygen, even in a still basin, and oversaturate it with the products of decay.

XX. An investigation of the pollution from street wash was begun, but suspended for lack of time and convenient places for systematic sampling; some consideration was given to its proportion of putrescible elements, quantity and control, and to the chemical analyses of a few samples.

Two samples were taken near the beginning of a gentle rain from what is probably as dirty a street as could be found anywhere tribu-

tary to the Charles, a street having much heavy teaming that pulverizes the horse manure, and with a very uneven granite block pavement, not easily swept clean; these samples thus plainly representing conditions more than tenfold worse than those ordinarily prevailing in the streets in the area tributary to the Charles. These samples were found a little worse than those reported from London in evidence, p. 422. But it was concluded, after inspecting much of the territory whose street wash is tributary to the Charles, that the chance of serious offence from this cause from the streets, as now cared for, was too remote to affect this problem very seriously, and that it could be readily provided for in the designs for new structures.

XXI. Frequent chemical and bacterial analyses of water above Watertown dam have been made, to determine its purity, its surplus of oxygen and its capacity to receive sewage without offence.

The summer flow entering the basin at Watertown is frequently found presenting an unattractive appearance from dye stuffs, factory wash water, etc. The organic matter in this water would not, owing to its nature and limited amount, putrefy under summer conditions in a still basin, but, on the contrary, with its exposure to air and oxidation of the impurities, its condition would continually improve.

It is desirable, however, that certain of the factory wastes now entering should be diverted to the sewers.

XXII. Expert biological examination has been made concerning the conditions favoring life of bacteria and other micro-organisms, plants and animals within the present Charles River basin and the Fens basin, and within the mud flats exposed at low water, in order to learn more about the capacity of the water in the proposed basin for self-purification.

The general result of these investigations has been favorable. Of special interest is the biologist's report, after full investigation, that the Fens basin presents no fair criterion by which to judge the proposed Charles basin, for reasons which he points out.

XXIII. Several lines of chemical research have been undertaken on behalf of the committee on Charles River dam, at the Lawrence Experiment Station of the Massachusetts State Board of Health, upon the comparative rapidity of exhaustion of the dissolved free oxygen in the fresh water taken from the Charles River above Watertown dam and in the salt water of the present Charles basin, also upon the relative capacity of fresh and salt water to receive and oxidize various percentages of sewage pollution without developing putrefaction or causing offence.

Fresh water is found unmistakably superior to salt water in its capacity to receive pollution without the production of offensive odors. Salt water is found to precipitate the matters held in suspension in sewage much more rapidly than fresh water, and a salt or brackish water basin like that in the Fens therefore tends to a concentration of these impurities in the form of putrefying sludge banks, — far more so than would be found with a fresh water basin.

The "self purification" of polluted water (which is brought about through bacterial agencies) is found to go on as rapidly in still water

as in running water, and probably more so. The main requisite to this self-purification is found to be an abundance of dissolved oxygen, and this upland water of the Charles is found to be well supplied with dissolved oxygen. The laboratory tests indicate that if only the pollution entering could be thoroughly diffused, this water from the upland Charles, of the most polluted quality found coming over the Watertown dam, could absorb an amount of pollution many times greater than that which would come from the continual discharge of the sewage of 13,000 persons.

XXIV. Continuous gaugings of the twenty-four hour flow of upland water past the Watertown dam, by means of weirs, have been maintained for two months, and the water-power records of the Boston Manufacturing Company at Waltham for twenty-five years past have been carefully reviewed, in order to learn with all practicable accuracy the flow of fresh upland water, by which the sewage and street wash entering the basin will be diluted in summers of extreme drought.

We find that the flow of upland water is for long periods in summer sometimes much less than that indicated by analogy from the gaugings of the Sudbury, and that the factory sometimes holds back nearly the entire flow of the stream by storage in its very large mill pond for several weeks at a time. The result of this is that under exceptional conditions of extreme drought less fresh water may enter the basin than was assumed by the experts at the hearings, perhaps not more than from 10 to 20 cubic feet per second for a month at a time.

Pollution the Main Question.

The present sources of pollution, the quantity they discharge and the treatment required to remove this pollution or to make it inoffensive, are the great questions to be considered in deciding upon the advisability of the proposed dam, and the questions which most profoundly affect the cost of the whole enterprise, according as one remedy or another must be provided: whether salt water must be admitted in large quantity for flushing, and large sluiceways provided, adding perhaps $200,000* to the cost, or whether or not large and expensive † intercepting conduits along the margins of the basin must be provided for conveying this polluting mixture of sewage, street wash and storm water to tide water below the dam; whether separation of sewers from storm water drains may be done gradually and conveniently, or must be pushed ahead vigorously, with large immediate expenditure; whether the main drainage conduits should promptly be relieved, wholly or in part, of the improper burden imposed, by using them for storm water drains from the Church Street, Dover Street and Dedham Street drainage districts, —*the solution of these and sundry other important problems depends mainly upon finding out just what amount of sewage overflow into the river is permissible without offence, and how largely in excess of this amount, if any, is the prospective amount of sewage that would naturally enter the future basin.*

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* J. Herbert Shedd (p. 369) estimates $163,500 for certain sluiceways; Percy M. Blake (p. 237) estimates that a certain other design for tidal sluices would add $225,000 to the cost of the dam.

† It was estimated by the city engineer of Boston, in January, 1902, that a conduit built within the embankment along the entire length of the Boston side, from Ashby Street or St. Mary's Street, to below the dam, a distance of about 2.40 miles, sufficient to take *all surface water and all overflows in heavy storms* from Stony Brook and Muddy River (2,000 cubic feet per second from 8,900 acres of Stony Brook plus 831 cubic feet per second from 3,700 acres of Muddy River, above Brookline Avenue gate house), or of capacity nearly the same as the new Stony Brook channel, would cost upward of $2,000,000, as appears below. Of course by proportioning a conduit to carry only the "first wash" from sewers and streets to below the dam, or by providing capacity sufficient only for moderate storms, letting the surplus of heavy storms overflow into the Charles River basin, as now, the cost would be very much less, as appears by the second estimate below.

For Greatest Storms. Stony Brook and Muddy River.

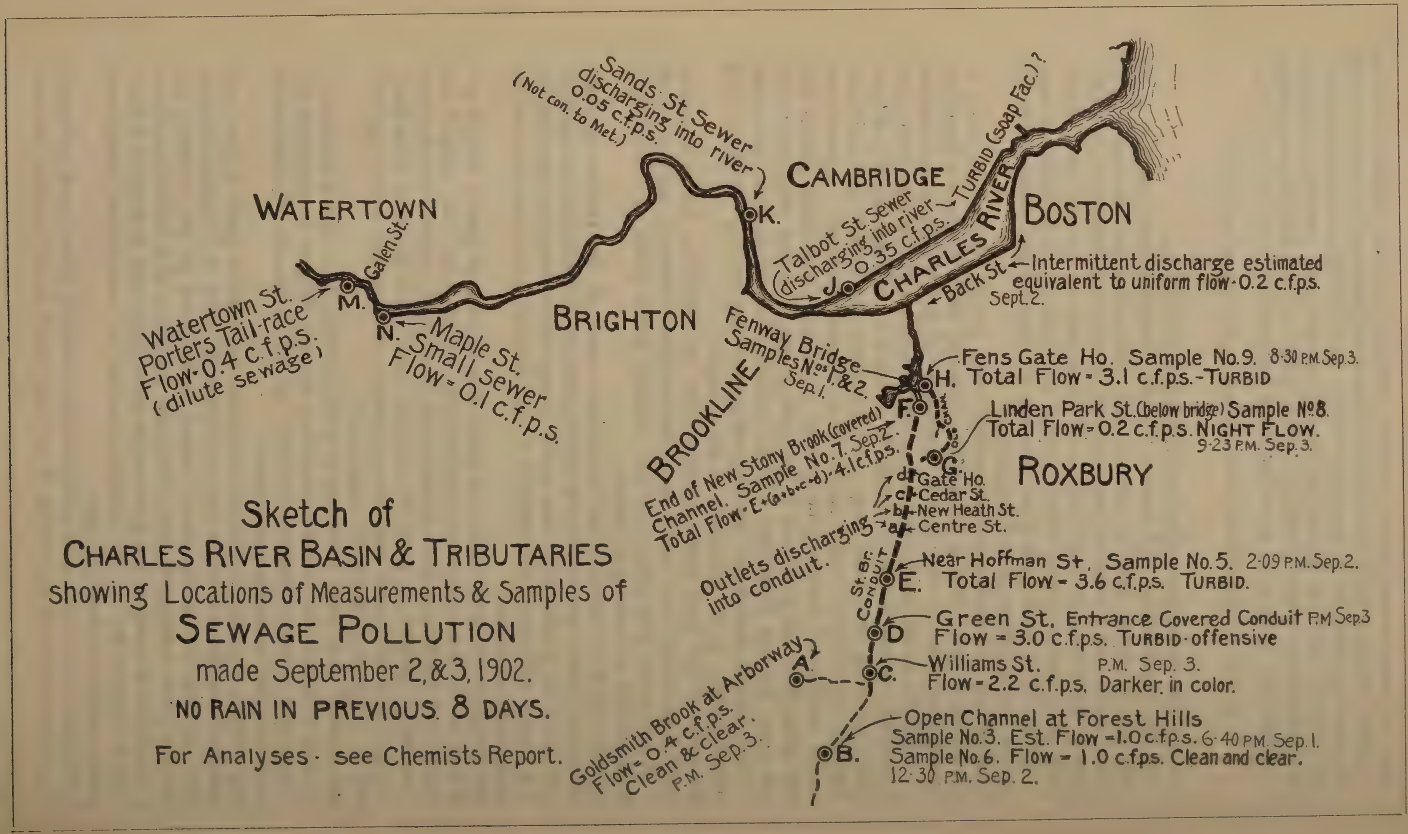
2,400 lineal feet circular, 7 feet 3 inches diameter, Ashby to Deerfield, at $25,	$60,000
1,300 lineal feet horseshoe, 12 feet by 12 feet, Deerfield to Fens outlet, at $45,	58,500
7,300 lineal feet double, each 20 feet wide by 14 feet high, Fens outlet to Charles Street, at $190,	1,387,000
1,700 lineal feet bottom at —1.0, Charles Street to dam, 600 feet above Craigie, at $213,	362,100
Connecting six existing sewer outlets,	6,000
	$1,873,600
Add 10 per cent.,	187,360
Total, sufficient to hold and convey the entire flow from the most severe storm yet on record,	$2,060,960

(Note by J. R. F.: A conduit of this great size is plainly unnecessary.)

For all Ordinary Storms and Overflows.

Channel from Ashby Street to Fens, as before, thence continue the 12x12 horseshoe section to dam, 600 feet above Craigie bridge.

2,400 lineal feet circular conduit, 7 feet 3 inches diameter, Ashby to Deerfield, at $25,	$60,000
1,300 lineal feet horseshoe conduit, 12x12 feet, Deerfield to Fens outlet, at $45,	58,500
7,300 lineal feet horseshoe conduit, 12x12 feet, Fens outlet to Charles Street, at $45,	328,500
1,700 lineal feet horseshoe conduit, 12x12 feet, Charles Street to dam, at $53,	90,100
Connecting six existing sewer outlets,	6,000
	$543,100
Add 10 per cent.,	54,310
Total,	$597,410



Sketch of
CHARLES RIVER BASIN & TRIBUTARIES
showing Locations of Measurements & Samples of
SEWAGE POLLUTION
made September 2, & 3, 1902.
NO RAIN IN PREVIOUS 8 DAYS.
For Analyses · see Chemists Report.
WATERTOWN
Galen St.
M.
N.
Watertown St. Porters Tail-race Flow-0.4 c.f.p.s. (dilute sewage)
Maple St. Small Sewer Flow = 0.1 c.f.p.s.
BRIGHTON
Sands St Sewer discharging into river 0.05 c.f.p.s. (Not con. to Met.)
K.
CAMBRIDGE
Talbot St. Sewer (discharging into river 0.35 c.f.p.s.
J.
TURBID (soap Fac.)?
CHARLES RIVER
BOSTON
Back St
Intermittent discharge estimated equivalent to uniform flow · 0.2 c.f.p.s. Sept. 2.
Fenway Bridge Samples Nos 1. & 2. Sep. 1.
BROOKLINE
H.
Fens Gate Ho. Sample No. 9. 8·30 P.M. Sep. 3.
Total Flow = 3.1 c.f.p.s. - TURBID
F.
End of New Stony Brook (covered) Channel. Sample No. 7. Sep. 2.
Total Flow - E + (a+b+c+d) - 4.1 c.f.p.s.
Linden Park St. (below bridge) Sample No. 8.
Total Flow = 0.2 c.f.p.s. NIGHT FLOW.
9·23 P.M. Sep. 3.
G.
ROXBURY
d Gate Ho.
c Cedar St.
b New Heath St.
a Centre St.
Outlets discharging into conduit.
St. Br. Conduit
Near Hoffman St, Sample No. 5. 2·09 P.M. Sep. 2.
E. Total Flow = 3.6 c.f.p.s. TURBID.
Green St. Entrance Covered Conduit P.M. Sep. 3
D Flow = 3.0 c.f.p.s. TURBID · offensive
Williams St. P.M. Sep. 3.
C. Flow = 2.2 c.f.p.s. Darker in color.
A.
Goldsmith Brook at Arborway
Flow = 0.4 c.f.p.s.
Clean & clear.
P.M. Sep. 3.
Open Channel at Forest Hills
Sample No. 3. Est. Flow = 1.0 c.f.p.s. 6·40 P.M. Sep. 1.
B. Sample No. 6. Flow = 1.0 c.f.p.s. Clean and clear.
12·30 P.M. Sep. 2.

The conditions of defilement of the new Stony Brook channel and the Fens basin are to-day very much worse than they were when the Joint Board made its report in 1894.

It is certain that a bad nuisance caused by sewage and insufficient flushing has existed in the Fens basin since 1897, and that these waters are far from possessing the cleanliness desirable in a water park, for they are fed by Stony Brook, which is polluted in dry weather by domestic sewage and some brewery drainage, and is in rainy weather still further polluted by storm overflows of sewage from a few old, badly drained, cesspool-like sewers.

The new "commissioners' channel" for Stony Brook has practically become a sewer, and, indeed, its upper middle portion is described by two experts, who have inspected it at my request, as "like a cesspool," and as "resembling a long septic tank."

The old Stony Brook culvert and channel between the Boston Belting Company's factory in Roxbury and the Fens gate house is also foul, containing long and deep deposits of putrefying sewage sludge, and is said to be in a hopelessly bad state of repair, with roof broken for considerable distances, and side walls undermined in places, and to demand reconstruction.

Personal inspection has satisfied me that the amount of sewage brought into the Fens through the new Stony Brook conduit and into the Charles by the old Stony Brook conduit is very much larger than would naturally be inferred from reading the statements made by the Boston officials, given in the volume of evidence.

It is certain that there are now several large areas of exceedingly foul, putrescent mud, from which gas bubbles constantly arise in warm weather, in the path down stream from the principal sewer overflow outlets on the Fens basin and in the Charles.

It is certain that under present conditions and on rare occasions, and for brief periods immediately after heavy rain and at low tide, there are floating in the Fens and in the Charles River broad patches of foul scum, containing undissolved human excrement and other objects disgusting when seen at close range or by persons boating. These occasions are brief and rare, and have not been the source of complaint, probably because persons seldom go boating in rain storms at low tide.

Although these badly infected areas probably cover never more than one-fifth of one per cent. of the entire area of the Charles basin, and are rarely seen, one sight of such filthy material may produce a feeling of disgust that will linger in the memory and detract from that sense of purity which makes water enjoyable.

At the same time, it is true that two or three years hence, with the high-level metropolitan sewer in use, and other work in progress completed, not one-twentieth part so much sewage will find its way into the Charles basin as there was entering it about twenty-five years ago, and not one-tenth part so much as was entering it ten years ago; and that the tendency is still toward further improvement that will in all probability more than offset the growth in population.

Various Problems concerning Pollution of Basin.

There are several of these pollution problems. The present deposits of sludge on a few relatively small parts of the bed of the Charles River basin, and the whole of the bed of the Fens basin, present one problem; fruit skins, melon rinds, chips, waste papers and other floating rubbish, another; the waste oil from power stations and gas works, spent dyes and wash water from factories, another; and the constant or dry-

weather discharge of sewage from the Beacon Street houses, and other sewage which has been alluded to in the evidence as not officially known to exist, presents another important problem; but *the great problem is that of the overflow of sewage in time of storm*, and the disgusting quantities of floating excrement that sometimes accompany it; for this overflowing sewage is by far the largest source of pollution, and *I have become convinced, by personal observation of the material coming out in time of storm, that statistics based merely on the proportionate duration of these storms do not give an adequate measure of the occasional extent or quality of this filth.* Appearances indicate that there is a concentration of the floating fæces, or that there is a dry-weather deposit taking place somewhere in the sewer system, which under certain infrequent conditions is flushed out into the Charles in the more vigorous overflows.

Disposal of Unavoidable Pollution.

Taking the largest reasonable estimate of the pollution from sewer overflows, street wash and other sources, it is but a small fraction of the quantity of manure that a farmer would make use of in cultivating an area of land equal to that covered by this basin; and, while it is probably true that earth and not water presents nature's most efficient laboratory for working over animal and vegetable wastes, it has appeared to me better to learn what can be done in taking care of this pollution by what has been termed "wet burning," or oxidizing through activities of life, rather than at the outset to plan works that would retard these activities by pickling the putrescible material in brine, and then allow the dead matter to form sludge banks and slowly putrefy, as it does now in the Fens.

The fixing of the safe limit of dilution beyond which there will be no offence when sewage and street wash are discharged into stagnant, fresh, brackish or salt water, is a problem toward which scientific attention has only recently been turned; and the rules quoted by the experts at the hearings and printed in the volume of evidence and arguments in this case appeared to rest on a narrow foundation, and to require verification by more recent experience before applying them under our conditions here; for a broad, quiet lake, with deep pockets, shoals and dredged channels which invite the current and may leave broad areas with very little current, may present a very different life environment from a running stream.

The investigation that apparently furnishes the basis for most of the opinions on the permissible amount of dilution given at these hearings referred to running streams (see Massachusetts State Board of Health report, 1890; special water supply volume, p. 791, article by F. P. Stearns, C.E.) and it included a warning against permitting sewage to discharge into mill ponds. I learn from Mr. Hiram F. Mills, C.E., chairman of the water supply committee, that this was put in more to guard against the drawing down and exposure of fouled mud banks, common in mill ponds, than from fear of the effects of stagnation. The very nature and use of a mill pond is that in dry summer weather it should be drawn down by day, exposing mud banks to the sun, and then filled up again by the storage of the night and Sunday flow.

The problem of how much sewage and fertilizing material from street wash can be taken care of in the water of the basin without offence appears to be essentially one of bacterial decomposition in the presence of oxygen, and of biological equilibrium; and *just where to draw the line in avoiding unnecessary expense* of construction is the question requiring further study.

For purposes of illustration and encouragement, I may quote the wonderful advances in sanitary science made through the studies of the Massachusetts Board of Health under Mr. Hiram F. Mills, Dr. H. P. Walcott and their earnest co-laborers, in the purification of sewage by intermittent filtration, where, by means of bacterial decomposition, sewage was *wholly transformed* into harmless, inoffensive effluents, as inoffensive and almost as safe as spring water, month after month and year after year, without "chemicals," commonly so called, and *without having to scrape any sludge off the surface*, by merely following the process of nature; or I may refer to the homely illustration of the well-kept kitchen garden, where bacterial action and vegetable growth render inoffensive a mass of manure, year after year, which, viewed only through statistics of pollution, might frighten one away from its neighborhood.

A mass of sewage belched forth from the outfalls in a few hours, at long intervals, at points far away from the main channel, as by certain of these storm overflows, presents a very different condition from the same total quantity, well dissolved, uniformly discharged and diffused promptly by the flowing and eddying of the running stream; but, after all of the studies made during the past seven months, and reported in detail in these appendices, I am led to believe beyond the shadow of a doubt that *sufficient flexibility in the design of the structures appurtenant to the dam can be provided to safely meet any conditions that can possibly occur*. I have sought to make outside estimates of the amount of this pollution, and to estimate the cost on designs that will surely be sufficient to prevent offensive conditions, having in view that, in the year that must of necessity intervene, pending legislative and other action, before actual construction of the dam, these problems, of how far it is necessary to spend money in lessening the pollution by building new sewers and by hastening the separation of storm water and sewage and of how to best take care of the pollution, can be further studied. Marginal conduits of the size and length that I have been led to recommend are, from certain points of view, perhaps unnecessary, but from other points of view — that of insurance of absolute safety, and that extreme cleanliness is a luxury worth paying for — I believe they should be provided. The details and dimensions of circulation weirs, the arrangements in the side of the marginal conduits for screening off the floating filth from the overflow in time of storm and flushing it back into the sewer when the storm is over, and the details for scouring the sediment from street wash and driving it along to the sump just inside tide gates at outlet of marginal conduit, much as is done in the deposit sewer of the main drainage, are details that can be studied and the necessary structures devised, I am sure, — *all within lines of absolute safety and reasonable economy.*

Conditions affecting Overflow of Sewage into the Charles River.

The storm overflow from sewers is by far the largest source of pollution.

There are now in the metropolitan district, along the Charles River and Stony Brook, about seventy-seven sewer overflows, through the most of which, in time of storm or melting of snow, sewage may escape into the Charles River basin. These are, in effect, safety valves, commonly one on each sewer district, each designed to provide an outlet through which any overload of storm water mingled

with sewage may escape before the sewer can become so gorged as to back up into cellars, catch-basins or streets.

These overflows are an absolute necessity, so long as sewage and drainage remain combined in one conduit.

The cost of making the main drainage and metropolitan sewers of anywhere near the capacity of the old combined common sewers and storm drains would have been absolutely prohibitive. Economy forbade making these long and costly conduits to Moon Island and to Deer Island more than a little larger than was required for the sewage proper, the household and factory wash water carrying waste. To-day, speaking generally, these main intercepters are found near their lower ends only sufficiently large to carry about two or three times the mean dry-weather flow; and this mean yearly twenty-four-hour flow is much smaller than the flow in the sewers during the forenoon of Monday or "washing day" in March or April when house drainage flow is heaviest and the ground water flow is large. These main intercepting sewers leading to the sea were, in fact, designed of size just sufficient to convey, in addition to the maximum sewage flow expected from a population then thirty years in the future, a flow of storm water equivalent to a depth of only one one-hundredth of an inch per hour of water from over the entire territory served. This receivable amount of storm flow is less than one-fortieth part of the rate of storm flow that sometimes occurs.

To further illustrate the impossibility of conveying more than a small fraction of combined sewage and drainage of Boston and Cambridge to the ocean outfall, we may quote the old rule until recently in common use for designing sewers to convey sewage and storm water combined, which was, to make the size sufficient to convey one-half an inch an hour in net depth of rain water from the area drained.

This half an inch an hour required for storm water is fifty times the one one-hundredth inch per hour actually provided for storm water in the metropolitan and main drainage systems. Hence the necessity for "sewer overflows" and "regulators," so long as the "combined system" of sewerage and drainage remain in service.*

The majority of these overflows are of the type shown in the drawings opposite this page.

The most common type consists of a gate through which the sewage must pass on its way to the intercepting sewer, the said gate being controlled by the action of a float in a chamber connecting with the intercepting sewer, so set and connected that when the height in the intercepting sewer reaches what is considered the greatest allowable height it will lift the float and shut the gate, and thus cut off any large quantity of water from entering. These gates in the Boston type are purposely fitted very loosely, and the cracks around the edges of the gate will doubtless in many cases allow as much liquid to enter the intercepter as would equal in volume the ordinary flow of sewage.

Others of the overflows consist merely of an open pipe set at a level near the top of the sewer, or an open gap and weir in the side of the sewer, so that when the sewage is backed up from down stream, or when the intercepting sewer is already so full that no

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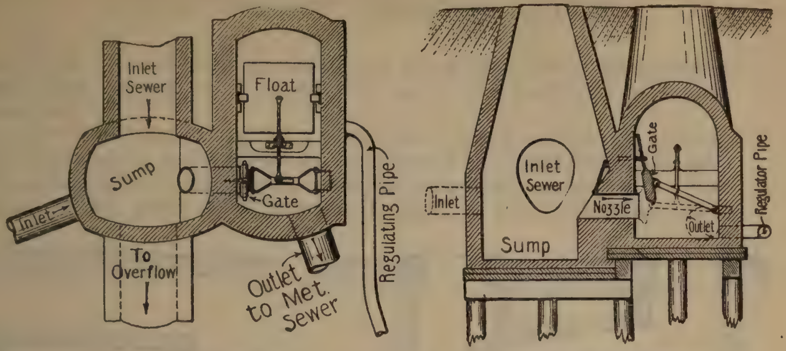
* I am told, by engineers who occupied important places on the engineering staff that planned the Boston main drainage works, twenty-five years ago, that the expectation then was that future work would tend toward a separation of the storm water from the sewage; and that, before streets were rebuilt and resurfaced, new sewers and drains would be built. Had this policy been carried out, the problem would now be far simpler than it is to-day, and the cost of separation would have been so small each year that it would not have been a burden, and expensive pavement foundations would not have been again subject to disturbance from this cause; but this was afterwards lost sight of, and no such far-sighted, comprehensive plan has been followed.

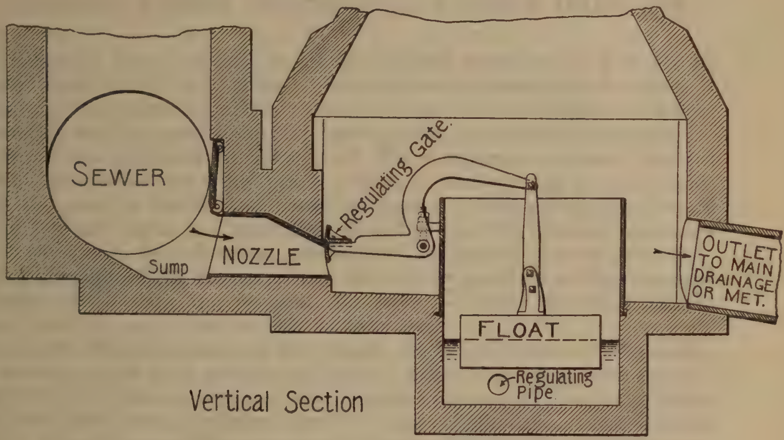


Horizontal Section   Vertical Section

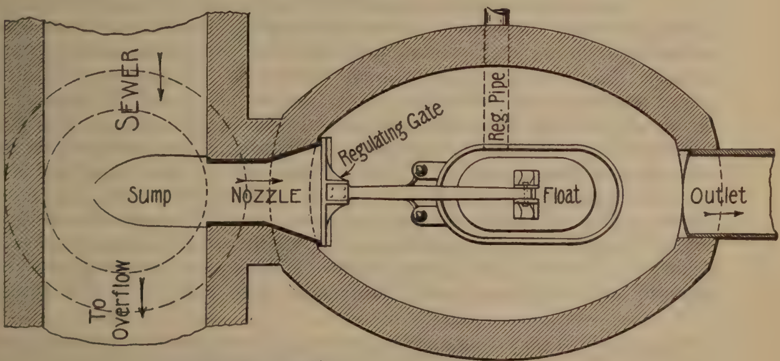
Plug Valve Type,
commonly used in Cambridge

SEWER REGULATOR

Scale 0. 1. 2. 3. 4. 5. Feet.



Vertical Section



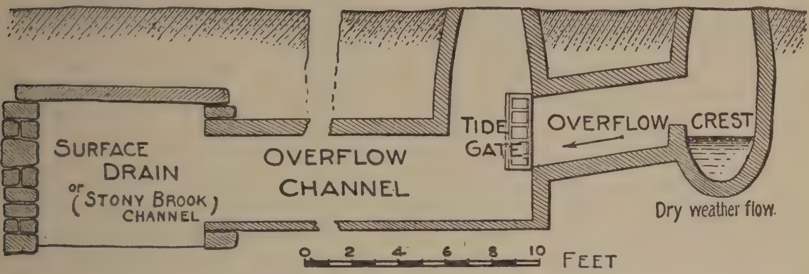
Horizontal Section

SEWER REGULATOR

Scale 0. 1. 2. 3. 4. 5. Feet.

more can be prudently admitted, the water from the common sewer will find an exit as it is backed up to the height of this open overflow.

In certain cases of overflows of the class just described, the backing up of the water which forces the overflows is produced by an automatic regulating gate, similar to the gate just described, and shown in figure opposite this page, which controls the level of the intercepting sewer



TYPICAL STONY BROOK VALLEY SEWER OVERFLOW

immediately down stream from this district regulator and holds its water level down to a point where only the predetermined volume is admitted to it, forcing all of the surplus out through those overflow channels that lie immediately up stream from the district regulator.

With the complete attainment of the "separate system," toward which the best engineering practice is now everywhere strongly tending, as safer to health and better in economy, and which has already been actively begun in Cambridge, in order to avoid flooding of cellars with sewage in low districts, and which I believe is sure to some time come throughout the larger part of Boston,* regardless of the proposed Charles River dam, the necessity for *these overflows of sewage into the rivers and the upper harbor will entirely cease.*

It is not difficult to make a safe, rough, outside estimate of the amount of sewage which thus enters the Charles; but a *very rough* estimate will not serve the present purpose, and to learn this amount of sewage entering the basin with precision involves many difficulties, for there are about seventy-seven different sewer districts with overflows entering the Charles, and among these widely different conditions are found.

It is at present difficult to predict precisely how often these overflows of sewage will take place, or what their precise duration or the precise quantity of sewage will be, merely from a study of the rainfall records and a study of the sewer plans. Some overflows are adjusted to act much more quickly than others; some overflows are set at a low elevation, and are thus prevented from overflowing at high tide; while others are not affected at all by the state of tide. On those sewers that are outgrown and almost overloaded by the maximum dry-weather flow the overflows are affected by very small and gentle rainfalls; while, for an opposite example, the overflows on the separate system sewers of Watertown would very rarely be made to discharge by the heaviest of storms,† perhaps not more than once in several years, even under the present

* Since writing the above, I have learned that in the report of the Boston sewer division of the street department for the year 1901 a very strong plea is made for immediately beginning the separation of storm water from sewage.

† The same sewage may nevertheless be rejected at a point farther down stream, as explained on p. 151.

unfavorable conditions prior to the completion of the high-level sewer. After the new high-level sewer is complete, it is probable that these Watertown and Waltham overflows will never again throw sewage into the river.

On a properly designed, separate system of sewers there appears no reason why overflows are needed, except to provide for the breakdown of the pumping system, a "cave-in," or accidents which have no reasonable probability of occurrence once in twenty years; and with the high-level sewer completed, and the separate system extended so that storm water would nowhere be received, there is no reason why the sewer overflow outlets along the upper portions of the Charles River basin in Newton, etc., should ever be again brought into action.

Quality of Discharge from Sewer Overflows.

Undiluted ordinary well-mixed sewage in motion is not particularly offensive. It contains only one part of offensive material in a thousand parts of water. The manure value of the average Boston sewage is estimated at only from 1 cent to 2 cents per ton.*

In the great majority of cases the sewage as discharged at these overflows is largely diluted by rain water, in the form of roof water, yard drainage and street wash; but in a few cases the discharge from some of the overflows on the separate system may be of undiluted sewage, when the trunk line is surcharged by rain water received at points further down stream. From what I have seen on the river, it appears that under some circumstances, and for a few times each year, the discharge may be much more offensive than undiluted sewage. In explanation, it appears that the form of construction of the sump and throttling gate at certain of the overflows may at times result in skimming off and concentrating the floating, fresh, unbroken excrement; so that when the storm water reaches a certain level, and while a large volume of liquid is going down through the intercepter, a great and disgusting mass of filth will be swept out suddenly into the Charles.

From recent personal inspection we find large deposits of sewage filth in the new Stony Brook channel, held back during dry weather by little accidental dams of brickbats and rubbish. There is reason to believe that many poorly drained pools exist in the covered channel of the old Stony Brook (which plainly receives sewage, although it has been said that none is "officially known" to enter it), and that there are still in use some ancient sewers of flat grade, in which large deposits may collect, and that in some of the large old "storage sewers" large deposits and accretions occur along the edges of the old invert. There is thus opportunity for some considerable deposits of the worst kind of filth to collect and putrefy in the interval between storms, and afterwards be flushed out into the Charles under the pressure and velocity from a sudden heavy downpour of storm water.

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* This has often been stated as 1 cent per ton. The following is the basis of our present estimate: The sewage of Boston does not contain over 3.5 parts of nitrogen per 100,000; that is, 0.07 pounds of nitrogen per ton. This, at 18 cents per pound, would be 1.26 cents per ton. Other ingredients would increase this slightly.

CONCENTRATED POLLUTION FROM THE FLUSHING-OUT OF DEPOSITS.

In Storage Sewers. — Some of the old sewers in the low land around the Back Bay were designed of very large size, in order that they might serve for storage basins behind the tide gates during heavy storms occurring at high tide. It is probable that the sluggish dry-weather flow in some of these permits lodgment and accretions of filth along the sides, until, after prolonged dry weather, a narrow stream of sewage flows along between banks of these filthy accretions, as has been actually observed in some of the large Boston metropolitan sewers; and that sometimes a sudden rush of storm water will come under just the right conditions to flush this through the overflow.

From flushing Ancient and Imperfect Sewers. — In some portions of the old Boston and Roxbury districts, and in portions of Cambridge, the sewer systems are patchwork affairs.* A few of the ancient plank box drains are said to be probably still doing service as sewers. Some of the sewers were begun many years ago, as short, independent drains to the nearest natural water course or the nearest branch of the Charles River estuary; later, as the habitable area was extended by filling marsh lands, these sewers and drains were extended; and later still, after the discharge of sewage into these natural water courses had become intolerably offensive, trunk sewers were extended along the water course, or the channel of the brook was covered by a culvert or sewer; and later still, the intercepting sewers of the main drainage system and of the metropolitan system were built, cutting across the outlet ends of the old sewers and drains, for gathering up their discharge and taking it out into the sea.

I am told there are some of these ancient sewers still in use that have very flat grades, or in some cases probably contain sags; and it appears possible that some of these may, therefore, act like long cesspools, and gradually fill up with filth, until some sharp, heavy shower puts on pressure and velocity enough to scour them out into the Charles.

The successive changes and extensions and reinforcements of sewers have in some localities resulted in a complicated system. In some places there are three parallel sewers in a street, side by side. In some few cases the extension is smaller than the original sewer that enters it, and, with bottoms at same height, the top of the extension is lower; and when the sewer is gorged in a heavy storm, this higher section may possibly form an elongated chamber, in which the floating filth may be skimmed off and held back for a time, to be discharged as the storm water lowers.

What I have myself seen, and what I have been told by drawbridge keepers and Fenway caretakers and policemen having beats near certain outlets, indicate that on rare occasions the polluting material that comes out is very much worse than would be expected from an ordinary modern sewer outfall; and the circumstances stated above explain the concentration of filth actually found floating in the Charles River basin on rare occasions under present conditions.

It appears practicable to so construct the marginal conduits hereinafter described that much of this floating filth can be held back while the liquid sewage flows out beneath the surface; and to so arrange that, after the storm is over, this floating material can be flushed back into the metropolitan channels by a small, quick-flowing volume of water

* The statements in pp. 13-15 of Mr. Eliot C. Clarke's report on "The Boston Main Drainage, — 1885," are of interest in this connection.

from the basin. Therefore, after giving this matter much attention, I am led to conclude that this occasional discharge under present conditions of a great volume of exceedingly filthy material does not necessarily signify any occasional serious fouling of the proposed basin.

Possibility of Sewage Overflow due Accidents to Tide Gates.

It appears that if, because of any accidental derangement or obstruction, a tide gate system upon any one of perhaps forty different overflows fails to close, this accident would admit a large flow from the Charles River to the intercepting sewer, sufficient, perhaps, to lift the floats and close the regulators (or rejectors), and so force nearly all of the sewage of that neighborhood out into the Charles River basin, during a few hours on each tide.

While one tide gate or another is not infrequently found blocked open after a storm, those on the Boston side are in nearly all cases set in pairs, one behind the other, and, so far as reported to me, both have seldom or never been found blocked at once; and it is understood to be the rule at present to inspect all tide gates after each storm. Nevertheless, a study of the clock gauge charts from the Charles valley sewer shows several periods of successive high depths in that sewer that coincide so remarkably with the times of high tide as to indicate that these tide gates do sometimes leak.*

Since the average pressure against the tide gates will, under the proposed conditions, with basin at grade 8, be greater than now and much longer continued, the conditions favorable for leakage inward through the tide gates will be much increased.

After all, it appears that the discharge of sewage into the basin because of an obstructed tide gate, with the arrangement of double gates now found on the Boston side, will not happen very often, and will be shown by the sewer clock gauge and the pump records, and that the quantity so entering from one or two districts for a few days is too small to affect the answer to our main question. A new and perfected form of tide gate has recently been designed in the Boston city engineer's office, which appears certain to meet all requirements.

On the Cambridge side many of the tide gates are single, and there have been sundry instances of bad leaks, some of which have produced overflow of sewage when there has been no rain (see official correspondence, chief engineer Metropolitan Sewerage Commission, about April 22, 1898). In the course of our own measurements on the Cambridge side we observed one case of a single tide gate leaking, several days after a storm, so badly as to double the flow in the sewer.

It is plain that every one of the single tide gates on a sewer overflow should be made double, and that the inspection of all should be made easy.

Overflows of Sewage from Separate System in Time of Storm.

The fact that a group of overflows do not act in a given storm may be no proof that all of the sewage which flows past them is not thrown out into the river at some overflow or district regulator farther down

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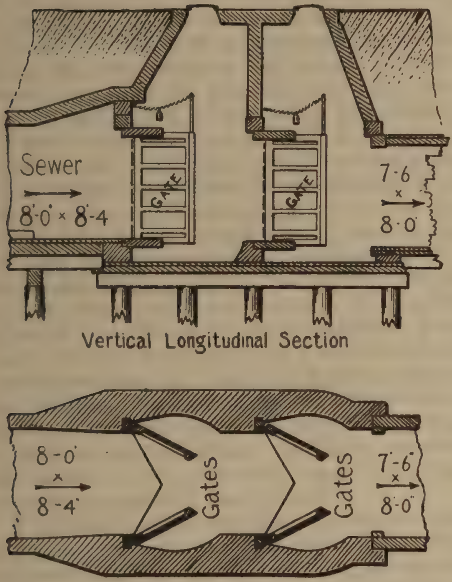
* The following are examples of large increase in depth in the Charles valley sewer when there had been no previous rain, and in which this increased flow corresponded in time with the rise of the tide. The proof that this was due to a leaky tide gate is not complete: —

April 17, 1902, 8 A.M. to 4 P.M. Beginning one hour after high water, depth rose so as to fill sewer by 1 P.M., and it continued full until midnight, and then rapidly subsided.

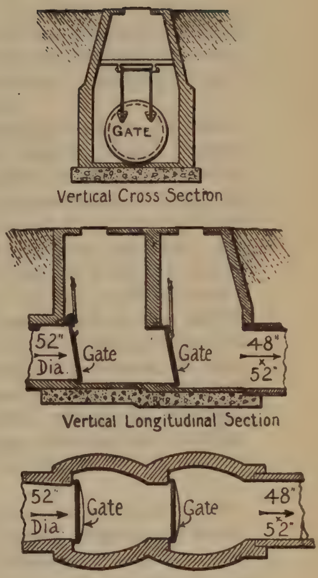
June 5, 1902, 11 A.M. to 1 P.M.

June 18, 1902, 9 to 12 A.M. Beginning at about time of high water flow increased to about double the normal for about six hours, and then rapidly subsided.

Types of Tide Gates



Tide Gate Chamber for Sewer "Double Barn Door Type"



Tide Gate Chamber for Sewer - "Flap Type"

Scale. 0 1 2 3 4 5 6 7 8 9 10 Feet.

stream, by reason of an excess of storm water entering at a point farther down stream, and so filling the main drainage sewer that no addition can be received from the up-stream portion.

For example, *the sewage collected in the separate systems of Newton, Watertown and Waltham, from which storm water is rigidly excluded, may all be crowded out into the Charles River, under present conditions*, by the excess of storm water freely admitted to the main drainage system through the main inlets from the Church Street, Dover Street and Dedham Street districts; on which inlets, because of danger of flooding cellars by storm water, and because proper surface drains have never yet been provided, rejector gates are not used at all.

I am told that a difference of opinion has long existed between the city engineer of the Boston sewer department and the engineer of the metropolitan sewers,* on the question of whether Boston really pumps *any* of the Charles River valley sewage during a heavy storm, or lets it *all* overflow into the Charles River.

It may be said, with approximate truth, that in exceptionally severe storms the main drainage engines are devoted mainly to pumping storm water away from the low districts, while the sewage is mostly turned out into the Charles River and the upper harbor.†

Prior to the completion of the new main drainage works, in 1885, cellars in the low-lying, poorly drained Church Street, Dover Street, Beach Street and Dedham Street districts were often flooded in severe storms. Instead of attempting to cure this by the construction of special storm-water drains, which should receive the street wash and perhaps the roof water, only taking drainage from low cellars into the new deep main drainage sewer, the district was relieved by freely draining *all* the storm water into the new intercepting sewers; and, as stated above, it is believed by some engineers who have studied the matter very carefully that this storm water crowds out the mingled sewage and storm flow from the combined districts lying farther up stream, in Boston, Brighton, Brookline, and crowds out the sewage received undiluted and unmixed with storm water from the separate sewers of Newton, Watertown and Waltham. Similarly, the sewage collected in the separate sewers of West Roxbury may be, in time of storm, all or nearly all crowded out into Stony Brook.

This feature of the crowding out of the sewage from a separate system, into which no storm water enters, because of the filling of the main drainage sewers by storm water entering at points farther down stream, will retard the lessening of the pollution of the Charles by means of the gradual separation of storm water from sewage in the Stony Brook district; for, although one overflow may thus be stopped, the same sewage may be forced out into the Charles at a point farther down stream in the few storms of exceptional severity.

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* Mr. Wm. M. Brown, chief engineer metropolitan sewers, tells me that the late Charles H. Swan, C.E., investigated this matter very thoroughly, and found that these unrestricted inlets will frequently admit all the water there is room for in the main drainage sewer.

† See Report State Board of Health, 1900, on discharge of sewage into Boston harbor, pp. 18, 19. "It will be seen, then, that when the rain or melting snow begins to increase the flow in the common sewers, all of the water mingled with the sewage enters the main drainage system until the main drainage sewers are filled to the height at which the regulators are set to close. Then, if the flow of rain water into the tributary sewers continues, the regulators close automatically, and very nearly all of the mingled sewage and storm water from all tributary districts, excepting the four districts already referred to, discharge into the waters about the city through overflow outlets, and the pumping system is then devoted to removing the mingled storm water and sewage from the four districts connected to the main sewer system without regulators, together with probably very little of the mingled storm water and sewage from other districts, until the storm subsides." Mr. Goodnough states, however, that this quantity entering from the unregulated sewers will not be sufficient to fill the main drainage sewers in other than exceptionally heavy storms.

Effect of adjusting Regulators to favor Particular Districts.

If the regulators in South Boston or near the South Bay were re-adjusted so as to promptly close the gates on the outlets from these districts at the beginning of the storm and cause all their sewage and storm water to promptly overflow, it would of course leave more room in the main drainage sewer available for receiving sewage from districts further up stream, and would thereby lessen the delivery of sewage into the Charles; but as between the regulators in the Charles water-shed, *when one district is favored at the expense of the rest, the result must always be to increase the pollution of the Charles.*

If there were the same proportion of surplus room available for storm water in the several secondary systems of each main sewer district, and if all of the seventy-seven overflows were of the same kind and all adjusted to reject the surplus in the same proportion, no one district being favored at the expense of another, and if there were no interference by the tide we could easily approximate to the quantity of sewage overflowing in each storm; but the complications noted in the foregoing pages make it more difficult to predict, from a mere study of the map and of the rainfall record, just what will happen under future conditions, than if we were dealing with a simple modern system that had been begun on a comprehensive plan, and these complications may have justified Mr. Hering's doubts (p. 437 of evidence) until after the investigation now being described. The wide extent of territory served and the diverse characteristics of the surface drainage in different localities add to the uncertainty of computing from theory just how much polluting material will be driven out into the Charles under a given rainfall record, as skilfully attempted by Mr. Goodnough, in pp. 105–113 of evidence.

Some actual measurement of this quantity of sewage overflowing, for confirming or qualifying these estimates, based on rainfall records, like Mr. Goodnough's, and those based on the Binney Street clock gauge alone, like Mr. Porter's, became very desirable. We have obtained this measurement by the methods to be described a few pages farther on.

Limits to Amount of Pollution Possible from Storm Overflows of Sewage.

At none of the seventy-seven different overflows have there been actual gaugings (as by weir measurement) of the quantity of sewage overflowing during certain definite periods, and the fact that the rise of the tide submerges the more important overflow outlets renders a continuous weir measurement impracticable; nevertheless, this quantity of sewage which escapes into the Charles River can be estimated with a tolerable degree of accuracy, providing we can ascertain the number of hours during which overflow of sewage has occurred. For we may, in considering a period of several months, assume that the rate of production of sewage proper is uniform; and so, if from any given district a rejection of the *entire* sewage flow was going on during 2 per cent. of the hours in three months, it could be fairly concluded that 2 per cent. of all the sewage was rejected, since the variations, as by the smaller rate of flow of sewage by night and its larger flow by day, would offset one another in this discussion of a long series of storms.

These overflows of sewage seldom occur except in time of storm, for, although accident or stoppage of pumps might cause them, our

examination of the pumping station records shows that trouble from stoppage of pumps has been experienced but rarely; and, under a system of inspection such as is said to now prevail, the overflows due to leaky or obstructed tide gates should seldom occur, and then for only a brief time and over a very limited area.

Total Hours of Rainfall, as a Guide to Total Hours of Sewage Overflow.

The ordinary rainfall record gives only the total depth of precipitation and the total duration of the storm, and we will first apply the results of this kind of rainfall record to our problem.

The other more modern and more scientific form of record is continuous. in the form of a chart, and so gives the mass curve and the rate from moment to moment, and will be considered later.

From an examination of the records of those few districts that have been provided with clock gauges that will be described later, it appears that rainfalls of a smaller depth than 0.2 inch seldom cause an overflow of sewage, however rapidly this amount of rain falls. This is in large part due to the large aggregate storage capacity in the sewers between the level of dry-weather flow and the level at which the regulator floats close these inlet gates. There are a few regulators where overflow is caused by a quick rain of only 0.10 inch or 0.15 inch in total depth, but these are fairly offset by many localities where 0.25 inch or more is absorbed without overflow, and by many storms in which the precipitation is so gradual that even 0.4 inch in depth does not cause overflow in the less thickly settled districts.

The total hours of rainfall and snowfall (at Chestnut Hill), after discarding those storms in which less than 0.2 inch of rain or melted snow fell, was: —

Years.	Summer Months, May to October (Total Hours).	Winter Months, November to December, January to April (Total Hours).	Total Hours for Year.
1899,	201	498	699
1900,	204	376	580
1901,	205	389	594
1902,	193	320(?)	513
Average,	201	396	597
Average percentage of entire time,	4.6	9.0	6.8
Maximum (in these four years) percentage of entire time,	4.6	11.0	8.0

Making no deduction for the petty storms which are excluded in the table above, the total hours of rainfall, some of which is hardly more than a mist, average about 11 per cent. of the entire time in this locality instead of the 6.8 per cent. found in the above table.

It is found, by methods to be described later: —

(*a*) That the total of the hours of sewage overflow for this large area as a whole is less than one-half of the *total hours* of rainfall, and does not exceed the total hours found in the table above, after discarding all the petty storms of 0.2 inch or less.

(*b*) That, during all of this period of overflow, only about one-half or two-thirds of the sewage produced is discharged through the overflows into the Charles River, the remainder meanwhile going down and out through the metropolitan sewers.

So that the actual percentage of the total sewage of this water-shed which reaches the Charles basin is more nearly 2 or 3 per cent. than the 4.6 per cent. foreshadowed in the table above by the total hours of rainfall in the storms exceeding 0.2 inch in total depth in the six warm months, and is only a half or a third part of the 7 per cent. that was so much in evidence at the hearings.

It is of interest to note that this overflow of sewage is smallest in the summer season, or in that portion of the year in which its presence would be the most offensive.

The reasons why this total amount of sewage overflowing is so much smaller a per cent. of the total sewage than the ratio of the total hours of rainfall to the total time are plain: —

First. — Rainfalls of less than 0.10 or 0.20 inch total depth, however rapid, are quickly soaked up by the ground, or taken care of temporarily in the surplus space in the sewer, and many rainfalls amounting to more than 0.20 inch in depth fall so slowly and reach the sewers so gradually that they will not close the regulator gates or cause overflows; moreover, a long storm commonly presents much variation in rate of rainfall at different times, and, during the periods of slight rainfall between its heavy showers, the run-off will frequently be so small that the metropolitan sewers can carry it for a few hours at a time without rejection. A large proportion of this territory sewered on the combined plan is semi-urban and has a large percentage of its lot area in lawn or sod which soaks up all but the most rapid rains as they fall.

(On the other hand, it is reported that there are a very few small districts in Roxbury, in which the existing sewers are so outgrown and overloaded that a very small excess of water, as from a quick rain 0.05 inch in depth or perhaps the extra flow of "washing day," will produce an overflow.)

Second. — High tide and the tide gates and the storage in sewers frequently modify the quantity discharged from those districts which, like Binney Street and Hereford Street, have their outlets set at a low level, by holding back the storm water in storage until several hours after the rainfall is over, and until after the metropolitan and main drainage regulator gates have opened and let much of this stored sewage out through the metropolitan and main drainage conduits.

The effect of the tide and the tide gate will always be toward lessening the amount of sewage discharged into the Charles, and, other things being equal, a sewer overflow set near low tide level will discharge a smaller volume of sewage overflow than one above tide level.

Third. — In all of these storms some portion of the sewage is all of the time being carried off by the metropolitan and main drainage conduits; and thus it happens in most districts that a rejection for 4 per cent. of the entire time results in only 2 to 3 per cent. of its entire amount of sewage being rejected.

The following causes act to increase the overflow: —

Fourth. — Although from fifteen minutes to forty minutes commonly elapse after the storm begins before the flood wave reaches the regulator gate and causes overflow, a heavy rain is always longer in draining off through the sewers than it is in falling. This we find adds from one-quarter to one-half hour to the period of overflow in the small districts. In the large districts, like Binney Street and St. Mary's Street, the clock gauges show that the flood wave commonly keeps the regulator closed for several hours after a heavy rainfall has ceased.

Fifth. — Snow slowly melting, as in shaded yards, may cause a rejection of sewage by the regulator gates during a longer period than an equal amount of rainfall.

Sixth. — It is stated, in explanation of certain of the dry-weather discharges, that we have found up the Stony Brook channel that some of the small outlets from old sewers into the newer trunk sewer occasionally become clogged, and then force more or less sewage out through their overflows, until the clogging is discovered and cleaned out.

While it is thus plain, in a rough, general way, from the rainfall record, that the total amount of sewage overflow will not probably exceed from 2 per cent. to 5 per cent. of the whole sewage produced by the tributary population, a more precise measure is needed; and all of the six disturbing causes just stated indicate that the rainfall record alone will not give so definite a guide as is desired to the hours and amount of sewage rejection, and that we must reinforce this by actual measurements of the period of overflow in typical districts.

Mr. Goodnough has skilfully based a more precise estimate on the hourly rainfall record by considering the relation of the run-off to the surplus capacity available for storm flow in the main intercepting sewers at the point where they leave the Charles water-shed; but since his method plainly disregards some of the serious complications and disturbing causes already referred to, such as effect of adjusting the regulators so as to favor one district at the expense of another, the effect of tide gates, the slow draining out of the storm flood wave, the complete rejection of all sewage from certain districts even in small storms, etc., I have thought it best to turn at once to the clock gauge records, already so much in evidence, and make the most of them.

Cambridge Sewer Clock Gauge Records.

The main reliance of several experts, whose opinions are in evidence in this case, for learning the amount of sewage pollution entering the basin has been certain records obtained under the supervision of the city engineer of Cambridge by means of self-recording clock gauges, which were intended to show the actual time and duration of each shutting out of the Binney Street sewage and drainage from the metropolitan sewer. These Cambridge sewer clock gauge records are described and quoted in the volume of evidence (Hastings, pp. 47–49; Brown, p. 122; Blake, p. 203; Porter, p. 413), and furnish the basis for sundry estimates to the effect that about 7 per cent. of the annual quantity of sewage for the entire tributary district finds its way into the Charles River.

This registering apparatus at the Binney Street sewer consists, in brief, of a chart moved by clockwork, upon which chart a line is drawn by a pencil, which is attached by appropriate levers, rods and wires to the automatic regulating gate by which the flow of sewage is controlled.

One of these clocks has been constantly in use on the regulator gate on the outlet of the Binney Street district, which drains one-third of Cambridge, and another clock on the Binney Street tide gate, since Dec. 1, 1898.

On the Bath Street overflow, Cambridge, a similar clock gauge was attached to the *tide gate* about a year later, or Dec. 3, 1899, and kept in constant use there until the spring of 1902, when it was moved to the Lowell Street *tide gate*, where it has been since in constant use. There has been no clock gauge attached to the *regulator gate* at either Bath Street or at Lowell Street.

In Boston, on the Charles River valley metropolitan sewer, on Huntington Avenue, near its point of present discharge into the Boston main drainage conduit, a clock gauge for continuously measuring only the depth in the sewer has been maintained by the engineers of the metropolitan sewers for some years past, and another clock gauge located much farther down stream on the main drainage system sewer is said to be maintained by the engineers of the Boston sewer department.

There has been no clock gauge or other record at any of the Boston sewer regulator gates until within the past few weeks, or until I set sundry clocks on the district regulator gates of the main drainage system at Ruggles Street and Cabot Street in the Stony Brook district and at the overflows from Hereford Street and St. Mary's Street, about Oct. 2, 1902.*

All of these sewer clocks and their attachments frequently get out of order. The foul sewer gases corrode the clockwork, and the charts some times swell and wrinkle in the dampness and stop the pen. The men who take care of those maintained by the cities are sewer foremen, not expert manipulators of delicate instruments; and so the records have to be scanned with much care and comparison with rain gauge, tide gauge, etc., and a good many missing lines have to be interpolated from a study of the rainfall records and the gauges at other sewers. We have found it possible to make good these defects in the six warm months with a good degree of accuracy.

The Binney Street Sewer Clock Gauge. — The Binney Street regulator controls one-third of the entire sewage of Cambridge that is tributary to the Charles River branch of the north metropolitan sewer, and serves about a tenth part of the entire population in the district tributary to the Charles, and is the largest district overflow found anywhere on the metropolitan sewer system. It is situated under somewhat peculiar circumstances, in having a metropolitan district regulator standing only twenty-five feet down stream from it, which metropolitan regulator may reject and throw back a part of the storm water that these Cambridge regulators might admit.

Moreover, there is understood to be, in Commercial Avenue, at Lechmere canal a twenty-four-inch connection from the Somerville or Bridge Street overflow that connects freely into the Binney Street district. This connection is long and small, and, in view of the similar forces at work in both of these adjoining districts in time of storm, it does not appear that this connection can introduce serious error into our conclusions.

This metropolitan regulator is now adjusted to admit about forty cubic feet per second, which is equivalent to about twenty-eight million

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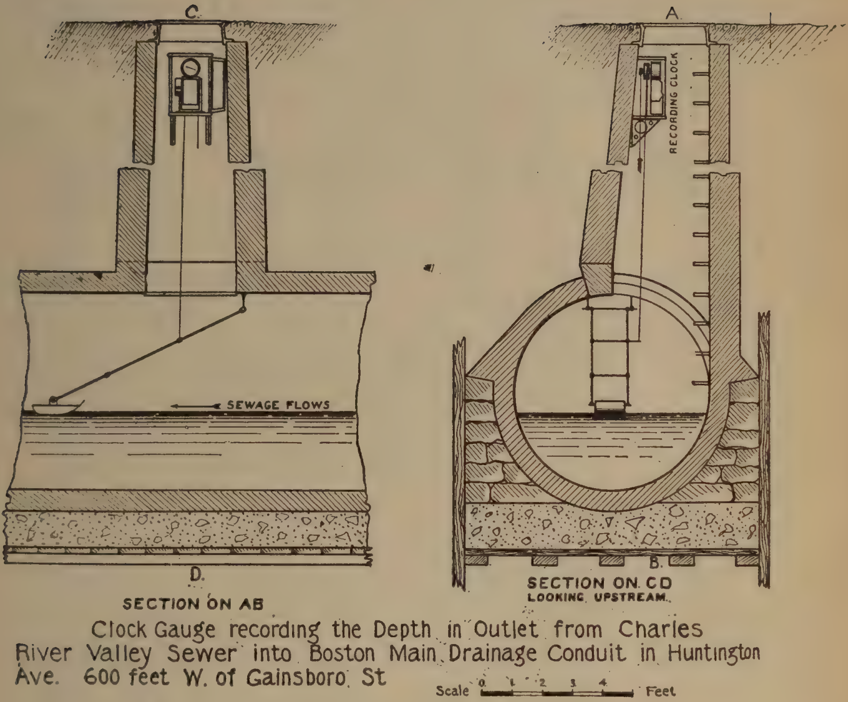
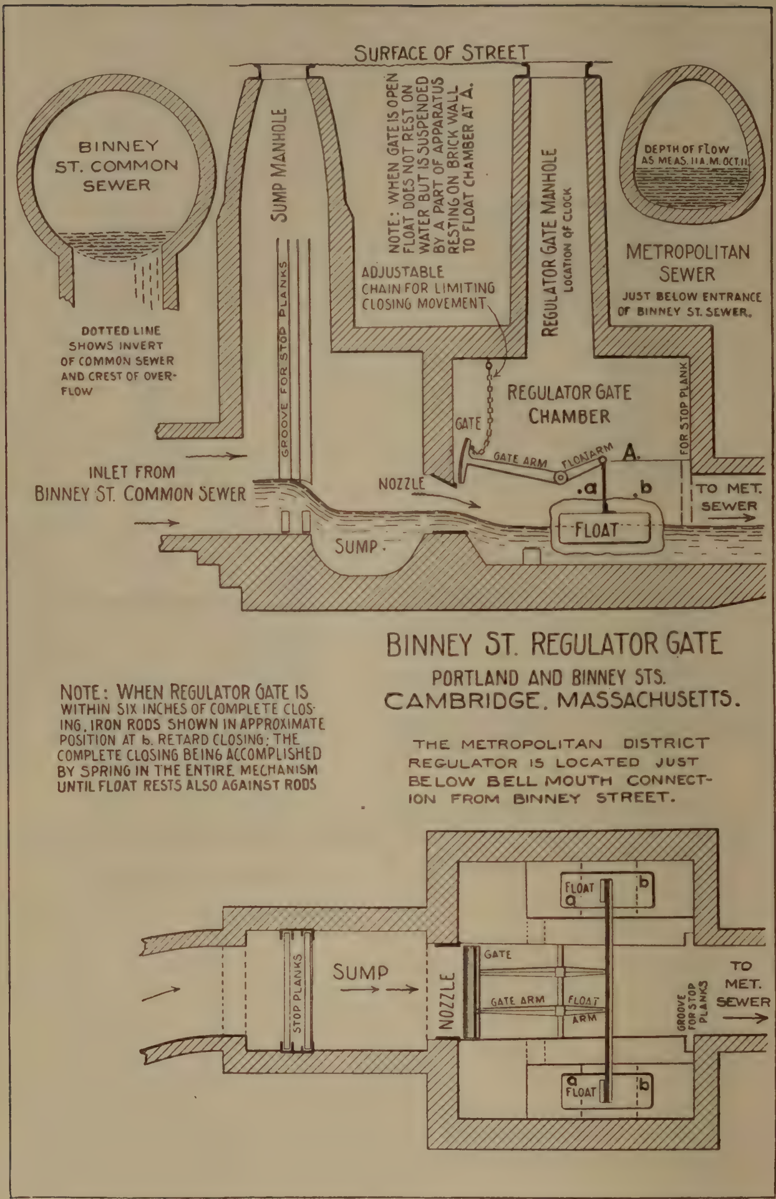
* I was very desirous of setting several more of these clock gauges in representative locations in other sewer overflow channels, but delay in receipt of the apparatus, difficulty in making the mechanism work in the foul, corroding air of a sewer man-hole, and the pressure of other work, have prevented.



Clock Gauge recording the Depth in Outlet from Charles River Valley Sewer into Boston Main Drainage Conduit in Huntington Ave. 600 feet W. of Gainsboro St


SURFACE OF STREET
BINNEY ST. COMMON SEWER
SUMP MANHOLE
NOTE: WHEN GATE IS OPEN FLOAT DOES NOT REST ON WATER BUT IS SUSPENDED BY A PART OF APPARATUS RESTING ON BRICK WALL TO FLOAT CHAMBER AT A.
REGULATOR GATE MANHOLE
LOCATION OF CLOCK
DEPTH OF FLOW AS MEAS. 11 A.M. OCT. 11
METROPOLITAN SEWER
JUST BELOW ENTRANCE OF BINNEY ST. SEWER.
DOTTED LINE SHOWS INVERT OF COMMON SEWER AND CREST OF OVER-FLOW
GROOVE FOR STOP PLANKS
ADJUSTABLE CHAIN FOR LIMITING CLOSING MOVEMENT
REGULATOR GATE CHAMBER
FOR STOP PLANK
GATE
GATE ARM
FLOAT ARM
A.
INLET FROM BINNEY ST. COMMON SEWER
NOZZLE
.a
.b
TO MET. SEWER
FLOAT
SUMP
BINNEY ST. REGULATOR GATE
PORTLAND AND BINNEY STS.
CAMBRIDGE, MASSACHUSETTS.
NOTE: WHEN REGULATOR GATE IS WITHIN SIX INCHES OF COMPLETE CLOSING, IRON RODS SHOWN IN APPROXIMATE POSITION AT b. RETARD CLOSING; THE COMPLETE CLOSING BEING ACCOMPLISHED BY SPRING IN THE ENTIRE MECHANISM UNTIL FLOAT RESTS ALSO AGAINST RODS
THE METROPOLITAN DISTRICT REGULATOR IS LOCATED JUST BELOW BELL MOUTH CONNECTION FROM BINNEY STREET.
FLOAT
a
b
STOP PLANKS
SUMP
NOZZLE
GATE
GATE ARM
FLOAT ARM
GROOVE FOR STOP PLANKS
TO MET. SEWER
a
FLOAT
b

gallons per day. (I have been told, but cannot vouch for the statement, that the large amount of water taken into the metropolitan sewer from the large pork-packing works in Somerville, a short distance below these regulators, compels some restriction here.)

The sole and only clock gauge *on a regulator gate*, within the district tributary to the Charles (until very recently), has been the one at Binney Street; and since this must, of necessity, be an important guide for interpreting the rainfall records on terms of sewer overflow, it merits full description, for its conditions of operation are found far more complicated than is indicated by the brief descriptions presented in the evidence, or than appears at first view. Moreover, we found that a careful investigation was required to determine if the conditions under which it works are strictly representative of the average of all of the sewer districts that overflow into the Charles, because: —

First. — Its regulator gate leaks more than any gate found elsewhere.

Second. — Its leakage and adjustment of height or shut-off are so arranged as to favor the drainage from this low-lying district, at the expense of other districts farther up stream.

Third. — The large area and gentle slope of district and great length of trunk sewer prolong the period of run-off greatly, in comparison with other districts.

Fourth. — The low elevation of point of discharge in relation to tide level permits the frequent arrest of overflow by the tide gates.

Fifth. — The large diameter and great length of trunk sewer up stream from tide gates favor the storage and retention of a large volume of mingled sewage and storm water during the four, six or eight hours of high tide; and during all of this time in the lulls between the showers the stored surplus is draining out through the metropolitan sewer.

As a result of much investigation we find that, notwithstanding all these points of difference, the Binney Street sewer owerflow record agrees fairly well with that from the other large districts. Its tide gates and its large storage are found to lessen the amount of rejection, and, in the comparison with the average case, offset, in part if not in toto, the effect of its leakage, its favoring adjustment, and its great drainage area.

We will review all these matters at some length because of their importance in interpreting the record

The Leakage of the Binney Street Regulator, when shut.

This Binney Street regulator gate fits much more loosely against its seat than any other examined, thus (intentionally, perhaps) permitting much leakage while the gate is closed to the limit. We found by measurement that the width of space between face of gate and end of nozzle was from .06 to .07 foot. Its circumference is about 12 feet, and the area remaining open when gate is shut is thus about 0.78 square foot, and, assuming a coefficient of contraction of 75 per cent., the effective area of this leakage is 0.6 square foot. The head acting upon this leak when overflow is taking place is 6 to 8 feet. This head produces a velocity of about 20 feet per second. Therefore, this leak around the edges of this Binney Street regulator gate, when closed, will discharge somewhere about 12 cubic feet per second, — an amount which is doubtless in excess of the dry-weather sewage flow.

Interpretation of the Binney Street Sewer Clock Gauge Charts.

This Binney Street regulator gate is actuated solely by the water level in the metropolitan sewer. *Its chart is, therefore, nothing more than a "time and height" record of the water level in the metropolitan sewer between the limits of 2 feet 7 inches and 3 feet 5 inches depth,* 2 feet 7 inches being the depth of water at which the float begins to lift and shut the gate. This depth of 2.6 feet corresponds to a flow of about 30 cubic feet per second in the metropolitan sewer, which is 67 per cent. in excess of 18 cubic feet per second, the ordinary dry-weather flow. Three feet five inches is the height of water in the metropolitan sewer when the float has reached its limit of motion and the gate is shut to the bottom of its nozzle, but is leaking probably 12 cubic feet per second, as stated above.

From measurements of the apparatus that we have made and from a study of the movement of the float that moves the regulator gate in relation to the depth in the metropolitan sewer at Binney Street, not here reported in full, it appears probable that no overflow of sewage into the Charles River from the Binney Street district can occur while this regulator gate is shut to less than about seven-eighths of its full range of motion.

This is shown by the following computation: this gate nozzle is 2 feet high by 4 feet wide; an opening 3 inches in height, which is one-eighth of its full range of motion, therefore gives 1 square foot of aperture, and adding the .4 square foot of crack around edge of gate gives 1.4 square feet of gross area of orifice, which, with a coefficient of 75 per cent., becomes 1.05 square feet net effective area of aperture. This, with the 21 cubic feet per second velocity due to the 7 feet of head, would discharge the 22 cubic feet per second for which there is probably room in the metropolitan sewer.

Certain observations of the depth in the regular man-hole and in the metropolitan sewer just up stream from the metropolitan regulator, that have been made in time of storm overflow, confirm these conclusions, — that no rejection takes place unless gate is almost fully closed.

If the yielding of the stop rods lets the gate shut too far down, so that it opens at the top, as is said to have formerly been the case until the stop chains were added, this would not change conditions until the gap at the top was opened more than three inches; and, if opened more, this would simply cause the water level in gate man-hole to rise until the lessened head or orifice established equilibrium.

Therefore, our first rule for obtaining the period of sewage overflow from these Binney Street clock charts is to *include only the time during which the gate is shown to be within one-eighth part of fully shut.**

At those times when this Binney Street regulator gate is only partially closed, to such an extent that an opening of more than three or four inches is left beneath its bottom edge, our computation shows that the gate merely throttles the sewage, but does not back it up in the sump to height sufficient to cause overflow toward the tide gate. Reference to the profile of the north metropolitan sewer, published herewith, will show to how great a height this has to be raised before overflow begins.

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* The records for 1900 and 1901, reported on p. 48 of evidence, are found to have included all hours when more than one-half shut; those for 1899 included only the hours of almost complete closing.

The charts show that there is commonly some rounding off of the corners of the diagram at point of complete closing and of starting to open, due, no doubt, to the fact that the stop rods and the stiffness of the float connection interpose some extra resistance at the point of closing. The most of this falls within this one-eighth limit of height.

Conversely, from our computations summarized in table on following page, it appears that, during all of those periods while the Binney Street regulator gate is more than about 85 per cent. shut, about one-half of the sewage from the Binney Street district must be rejected and thrown out into the Charles River (excepting those periods while high tide and the tide gates hold the sewage in storage in the large trunk sewer).

The results of revision of the Binney Street overflow records are condensed in the following tables, and the headings to the several columns are given with such completeness that little further explanation is required.

All rainfall records at Chestnut Hill and at Cambridge city hall have been reviewed, to make sure that all storms should be accounted for in the summary of overflows, and interpolations have been made for missing sewer clock charts.

In estimating the per cent. of sewage rejected during these hours, the run-off has been called 50 per cent. of the total depth of rainfall, in order to allow for a proportion of impervious surface possibly larger than the average; and allowance has also been made for the larger proportion (.018 inch per hour) of storm water taken in at Binney Street. The method of computing this is given later, and its basis explained in detail.

Summary of Records of Binney Street Sewer Overflows, as revised from the Original Charts by F. H. Carter, C.E., November, 1902.

For the Six Warm Months (*May 1 to October 31*).

Month and Year.	Total hours of rainfall recorded at Cambridge city hall.	A. Total hours of rainfall at a rate too small to move the Binney Street regulator.	B. Total hours partial closing of regulator (not including periods before and after complete closing).	Total hours of complete closing of regulator gate.	Hours closed for other cause than storm.	C. Total hours complete closing of regulator gate with outflow prevented by tide gate.	D. Total hours of sewage partially rejected and discharged into Charles River.*	Mean per cent. of sewage discharged meanwhile into Charles River.†	Total hours equivalent of all sewage discharged.
1899.									
May,	23.4	19.4	–	1.9	–	1.9	–	–	–
June,	45.6	15.8	1.7	31.2	4.3	8.6	18.3	49	8.9
July,	42.7	9.1	1.0	40.3	–	3.8	36.5	38	13.9
August,	52.2	19.5	1.0	15.9	–	–	15.9	72	11.4
September,	54.5	26.9	8.0	23.2	–	4.5	18.7	74	13.9
October,	76.6	23.7	–	39.0	–	15.8	25.2	41	10.3
Total,	295.0	114.4	11.7	151.5	4.3	32.6	114.6	51	58.4
1900.									
May,	45.6	4.7	4.0	45.3	–	4.8	40.5	46	18.7
June,	45.5	7.6	–	29.5	4.3	10.0	15.2	47	7.1
July,	26.5	.7	–	34.3	–	13.1	21.2	32	6.8
August,	23.4	–	3.2	26.1	–	5.7	20.4	49	10.0
September,	42.8	14.0	–	30.5	1.3	1.2	28.0	61	17.0
October,	56.5	2.0	–	54.7	5.1	20.1	29.5	40	11.9
Total,	240.3	29.0	7.2	220.4	10.7	54.9	154.8	46	71.5

1901.									
May,	96.5	2.0	–	103.7	7.6	20.0	76.1	37	28.4
June,	29.0	18.5	–	15.4	–	12.4	3.0	75	1.2
July,	25.5	2.0	2.9	34.2	–	3.0	31.2	58	18.2
August,	47.3	28.0	–	25.8	4.6	9.9	11.3	80	9.0
September,	45.4	2.8	4.0	40.8	2.2	21.0	17.6	50	8.8
October,	26.2	4.0	–	21.1	2.6	1.6	16.9	55	9.3
Total,	269.9	57.3	6.9	241.0	17.0	67.9	156.1	48	74.9
1902.									
May,	24.7	18.7	–	4.5	–	4.5	–	–	–
June,	36.5	15.0	2.2	17.8	–	16.2	1.6	74	1.2
July,	43.1	9.6	–	21.5	–	9.4	12.1	69	8.3
August,	33.5	1.2	1.7	30.7	2.6	16.4	11.7	53	6.2
September,	42.6	4.9	1.7	23.9	–	21.6	2.3	79	1.8
October,	55.8	–	2.3	42.6	–	–	42.6	44	18.8
Total,	236.2	49.4	7.9	141.0	2.6	68.1	70.3	52	36.3
Average total hours in the six warm months,	210.3	60.0	9.0	188.5	8.6	55.8	123.9	48	60.3
Per cent. of total time,	4.8	1.4	.2	4.3	.2	1.3	2.8	–	1.4

The above shows: —

First. — That during the six warm months, in which alone there appears to be a possibility of serious offence, the period of sewage rejection from the Binney Street district averages only 2.8 per cent. of the entire time.

Second. — *That after making allowance for the sewage that flows down through the metropolitan all through the period of rejection, the proportion of the entire production of sewage in this 700 acre portion of Cambridge during the six summer months has averaged only 1.4 per cent. during the past four years.*

The possible errors of observation and computation will apparently not admit of this being more than 2.0 per cent.

Third. — Class C, in which are grouped those periods in which the high tide prevented overflow from Binney Street, is of interest for comparison with districts where outflow is less affected by the tide. Had tide gates not interfered, the total period of discharge at Binney Street in the six warm months would have been increased from 2.8 to 4.1 per cent.

Fourth. — Class B, in which are grouped those periods in which the movement of the regulator was too small to cause overflow, is of interest for comparison with other districts more sensitive in point of overflow. These partial movements if producing overflow would have further increased the total duration of overflows to 4.3 per cent. of the total time.

* Rejection of all sewage for 1 per cent. of the time corresponds to 7.2 hours per month.

† See p. 177.

Summary of Records of Binney Street Overflow, as revised from the Original Charts.

For the Six Cold Months (*January to December*).

MONTH AND YEAR.	Total hours of rainfall or snowfall.	A Total hours of rainfall at a rate too small to move Binney Street regulator gate (including snowfalls).	Hours duration of snow storms which did not move Binney Street regulator gate the same day, but which may have later moved Binney Street regulator gate.	B Total hours partial closing regulator gate insufficient to produce overflow.	Total hours complete closing regulator gate.	C Total hours complete closing regulator gate with overflow prevented by tide gate.	D Total hours sewage partially rejected and discharged into Charles River.		
1898.									
December,	86.0	-	-	89.0	68.1	20.4	47.7		
1899.									
January,	82.4	9.5	9.5	-	93.6	58.2	35.4		
February,	154.8	126.7	123.7	35.2	100.6	28.9	71.7		
March,	207.7	26.0	26.0	62.7	173.0	85.7	87.3		
April,	47.9	8.2	-	-	17.3	4.8	12.5		
November,	47.1	15.9	2.2	1.0	21.9	5.0	16.9		
December,	29.2	6.5	-	-	13.9	2.8	11.1		
Total,	569.1	192.8	161.4	98.9	420.3	185.4	234.9		
1900.									
January,	69.4	14.5	14.2	4.0	61.4	5.5	55.9		
February,	110.3	17.5	17.5	27.0	111.9	26.5	85.4		
March,	77.2	5.0	5.0	21.5	78.0	13.5	64.5		
April,	29.1	-	-	-	26.8	21.5	5.8		
November,	94.1	9.2	9.2	1.0	71.8	.7	71.1		
December,	49.3	17.0	17.0	22.0	43.5	18.8	24.7		
Total,	429.4	63.2	62.9	75.5	393.4	86.5	306.9		

1901.									
January,	76.0	67.0	67.0	6.0	15.0	–	15.0		
February,	22.0	22.0	22.0	9.0	–	–	–		
March,	99.5	4.5	–	–	109.3	4.9	104.4		
April,	124.4	–	–	30.0	145.2	42.3	102.9		
November,	53.7	17.7	17.7	1.0	24.0	5.0	19.0		
December,	94.2	22.0	22.0	11.5	125.6	27.8	97.8		
Total,	469.8	133.2	128.7	57.5	419.1	80.0	339.1		
1902.									
January,	35.0	22.0	22.0	–	32.8	8.9	23.9		
February,	85.5	34.5	34.5	6.0	127.8	9.7	118.1		
March,	73.5	17.5	10.0	96.2	79.2	38.8	45.4		
April,	53.5	–	–	8.5	57.8	22.8	35.0		
Total,	252.5	74.0	66.5	110.7	297.6	80.2	217.4		
Assumed for fall six months of 1902,	375.0	100.0	90.0	120.0	400.0	100.0	300.0		
Average, four years, six cold months total hours,	460.0	122.0	105.0	86.0	408.0	113.0	295.0		
Per cent. of total hours,	–	–	–	–	9.4	2.6	6.8		

As the final result of all this revision, we find:—

That for the whole year the period of overflow from Binney Street into the Charles averages 4.8 per cent. of the entire time, instead of the 6.3 per cent. indicated on p. 48 of evidence.

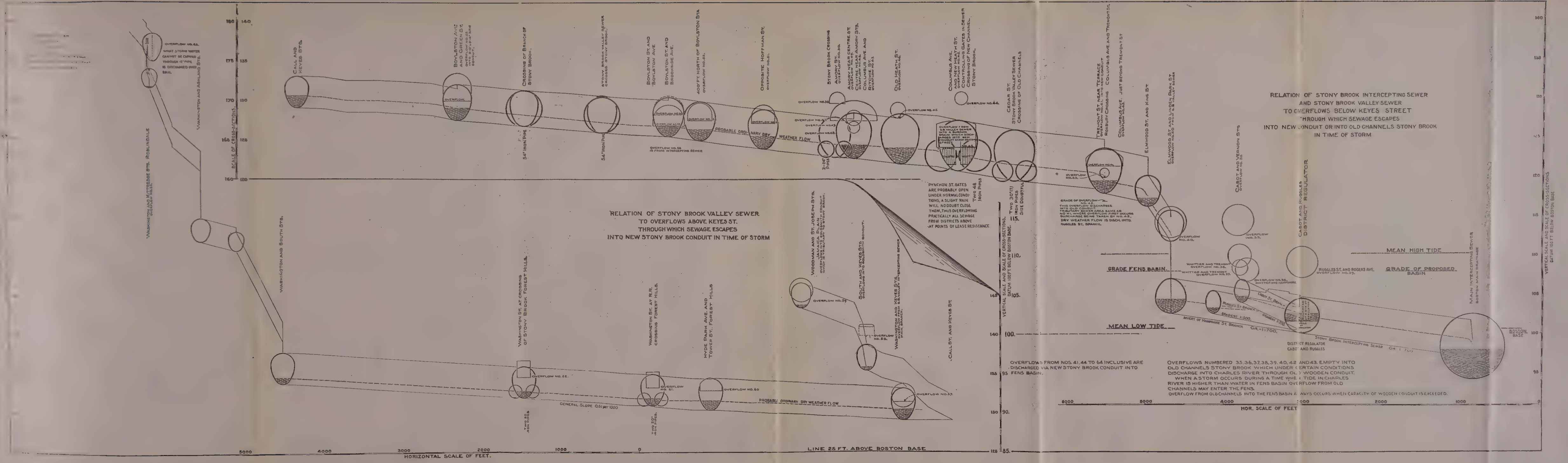
Results of Some Computations for finding the Amount of Storm Water that can be received into North Metropolitan Sewer from its Several Drainage Districts.

[See profile, Relation of North Metropolitan to Cambridge Sewer Overflows, etc., for further data.]

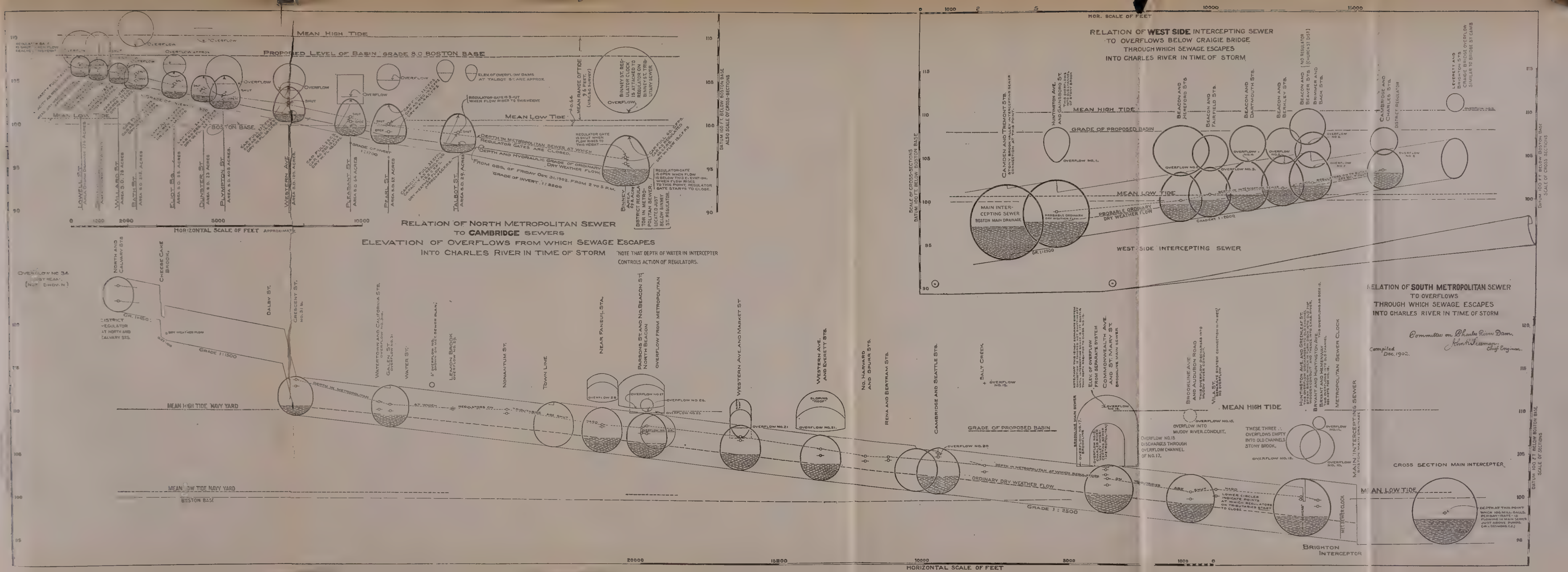
Drainage District.	Computed Delivery of North Metropolitan Sewer from Point just Down Stream from this Regulator.				Assumed Distribution of Dry-weather Flow of Sewage.		Measured leak of this regulator gate when shut hard, approximate (c. f. s.).	Maximum flow in metropolitan sewer just below this point in heavy storm (c. f. s.).	Maximum inflow receivable from this regulator in time of heavy storm. — Mingled storm water and sewage (c. f. s.).	Area of drainage district (acres).
	Latest recorded adjustment.			Computed delivery for this depth (c. f. s.).	From this district (c. f. s.).	Total to just below this point (c. f. s.).				
	Depth at which begins to shut (Feet).	Depth which shuts it hard (Feet).	Assumed working depth (Feet).							
Lowell,	1.27	1.44	1.38	5.2	1.4	1.4	.1	5.2	5.2	236
Sparks,	.90	1.37	1.21	4.4	.5	1.9	.1	5.3	Leak, .1	79
Willard,	.50	1.21	1.09	3.7	.2	2.1	.1	5.4	Leak, .1	28
Bath,	.90	1.69	1.49	7.2	1.5	3.6	.3	7.2	1.8	215
Eliot,	(?)	1.67	1.47	7.3	.4	4.0	–	7.3	Leak, .1	58
Dunster,	.95	1.56	1.41	6.6	.2	4.2	–	7.3	Leak, –	23
Plympton,	1.08	1.64	1.50	10.3	3.0	7.2	.2(?)	10.3	3.0	408
Western,	(?)	2.20	2.00	16.0	.8	8.0	.6	16.0	5.7	120
Pleasant,	1.55	2.10	1.96	15.3	.4	8.4	.3	16.3	Leak, .3	64
Pearl,	1.34	2.25	2.03	16.5	.4	8.8	–	16.5	.2	67
Talbot,	(?)	2.40	2.20	18.5	.2	9.0	–	18.5	2.0	29
Binney,	2.55	3.30	3.15	40.0	9.0*	18.0	12.0	40.0	22.0	698
Total to metropolitan regulator,	–	–	–	40.0	–	18.0†	–	40.0	40.5	2,025

* By estimation from rough weir measurement that we made, in proportion to entire flow found at district regulator.

† By proportion from estimate of chief engineer metropolitan sewers for all Cambridge in the wet season, February, 1901. In August, 19[illegible] a season of extreme drought, the quantity of sewage and ground water was only about 12 cubic feet per second. The larger [illegible]tity (18 cubic feet [illegible]nd) has been adopted, to allow for growth and extreme conditions, and because this larger quantity agreed more nearly with our rou[illegible] measurements in October, 1902.



RELATION OF STONY BROOK INTERCEPTING SEWER
AND STONY BROOK VALLEY SEWER
TO OVERFLOWS BELOW KEYES STREET
THROUGH WHICH SEWAGE ESCAPES
INTO NEW CONDUIT OR INTO OLD CHANNELS STONY BROOK
IN TIME OF STORM
RELATION OF STONY BROOK VALLEY SEWER
TO OVERFLOWS ABOVE KEYES ST.
THROUGH WHICH SEWAGE ESCAPES
INTO NEW STONY BROOK CONDUIT IN TIME OF STORM
PYNCHON ST. GATES ARE PROBABLY OPEN UNDER NORMAL CONDITIONS, A SLIGHT RAIN WILL NO DOUBT CLOSE THEM, THUS OVERFLOWING PRACTICALLY ALL SEWAGE FROM DISTRICTS ABOVE AT POINTS OF LEAST RESISTANCE
PROBABLE ORDINARY DRY WEATHER FLOW
GENERAL SLOPE 0.61 per 1000
OVERFLOWS FROM NOS. 41, 44 TO 64 INCLUSIVE ARE DISCHARGED VIA NEW STONY BROOK CONDUIT INTO FENS BASIN.
OVERFLOWS NUMBERED 35, 36, 37, 38, 39, 40, 42 AND 43 EMPTY INTO OLD CHANNELS STONY BROOK WHICH UNDER CERTAIN CONDITIONS DISCHARGE INTO CHARLES RIVER THROUGH OLD WOODEN CONDUIT. WHEN A STORM OCCURS DURING A TIME WHEN TIDE IN CHARLES RIVER IS HIGHER THAN WATER IN FENS BASIN OVERFLOW FROM OLD CHANNELS MAY ENTER THE FENS.
OVERFLOW FROM OLD CHANNELS INTO THE FENS BASIN ALWAYS OCCURS WHEN CAPACITY OF WOODEN CONDUIT IS EXCEEDED.
MEAN HIGH TIDE
MEAN LOW TIDE
GRADE FENS BASIN
GRADE OF PROPOSED BASIN
CABOT AND RUGGLES DISTRICT REGULATOR
MAIN INTERCEPTING SEWER
BOSTON BASE
LINE 25 FT. ABOVE BOSTON BASE
HORIZONTAL SCALE OF FEET.
HOR. SCALE OF FEET
VERTICAL SCALE AND SCALE OF CROSS-SECTIONS. DATUM 100 FT BELOW BOSTON BASE.
SCALE OF CROSS-SECTIONS
CALL AND KEYES STS.
BOYLSTON AVE. AND GREEN ST.
CROSSING OF BRANCH OF STONY BROOK.
OPPOSITE HOFFMAN ST.
STONY BROOK CROSSING
OLD HEATH ST.
CEDAR ST.
ELMWOOD ST. AND KING ST.
CABOT AND VERNON STS.
WASHINGTON AND SOUTH STS.
WOODMAN AND ST. JOSEPH STS.
SOUTH AND KEYES STS.
WASHINGTON AND KEYES STS.
CALL ST. AND KEYES ST.
WASHINGTON ST. AT CROSSING OF STONY BROOK FOREST HILLS.
WASHINGTON ST. AT R.R. CROSSING FOREST HILLS.
HYDE PARK AVE AND TOWER ST. FOREST HILLS
WASHINGTON AND ASHLAND STS.
WASHINGTON AND MYRTLEBANK STS. ROSLINDALE


RELATION OF NORTH METROPOLITAN SEWER
TO CAMBRIDGE SEWERS
ELEVATION OF OVERFLOWS FROM WHICH SEWAGE ESCAPES
INTO CHARLES RIVER IN TIME OF STORM
NOTE THAT DEPTH OF WATER IN INTERCEPTER CONTROLS ACTION OF REGULATORS.
MEAN HIGH TIDE
PROPOSED LEVEL OF BASIN GRADE 8.0 BOSTON BASE
MEAN LOW TIDE
BOSTON BASE
HORIZONTAL SCALE OF FEET APPROXIMATE
RELATION OF WEST SIDE INTERCEPTING SEWER
TO OVERFLOWS BELOW CRAIGIE BRIDGE
THROUGH WHICH SEWAGE ESCAPES
INTO CHARLES RIVER IN TIME OF STORM
HOR. SCALE OF FEET
GRADE OF PROPOSED BASIN
PROBABLE ORDINARY DRY WEATHER FLOW
WEST SIDE INTERCEPTING SEWER
RELATION OF SOUTH METROPOLITAN SEWER
TO OVERFLOWS
THROUGH WHICH SEWAGE ESCAPES
INTO CHARLES RIVER IN TIME OF STORM
Committee on Charles River Dam.
John R. Freeman, Chief Engineer.
Compiled Dec. 1902.
MEAN HIGH TIDE NAVY YARD
MEAN LOW TIDE NAVY YARD
BOSTON BASE
ORDINARY DRY WEATHER FLOW
GRADE 1 : 2500
CROSS SECTION MAIN INTERCEPTER
BRIGHTON INTERCEPTOR
HORIZONTAL SCALE OF FEET
DATUM 100 FT. BELOW BOSTON BASE. SCALE OF SECTIONS

Any Favoring of a Particular District increases the Per Cent. of Overflow from the System as a Whole.

The preceding table is of particular interest in showing that the percentage of sewage rejected at one district may differ greatly from that being rejected at the same time in an adjoining district. Here, for example, it is found that the Sparks, Willard, Eliot, Dunster, Pleasant and Pearl regulator gates will be shut hard and reject substantially all of their sewage in storms where the rate of rainfall exceeds say .08 inch per hour or perhaps less; and the Binney and Talbot regulators meanwhile be open and receiving a relatively large flow of storm water and rejecting little if any sewage.

The Lowell Street regulator, at the up-stream extremity of the north metropolitan system, is adjusted so high as to take in a quantity of storm water two or three times as great as its sewage flow before it closes; and this, once inside the metropolitan, cannot get out; and as it goes along it produces so great a depth that it shuts hard several of the regulator gates as it passes, forcing substantially all of their sewage out into the Charles River, as will be seen by the preceding table; and the various other regulators are adjusted at so low a point of closing that they preserve a vacancy in the sewer ready to take in a comparatively large volume from the low Binney Street district.

By rough measurement of the Binney Street sewage over a crude weir, formed of stop-planks in its regulator man-hole, and an almost simultaneous measurement of depth in the metropolitan sewer near the same point, we found that flow of sewage from the Binney Street district was nearly half of the whole, although its area is only a third of the area of Cambridge lying up stream from this point.

Our measurements and computations indicate that the Binney Street regulator should admit a run-off equivalent to .018 inches per hour in depth over its 698 acres; while the metropolitan district regulator, located only about 25 feet down stream from where the Binney Street sewer joins the metropolitan, admits about .011 inch per hour from its 2,025 acres; thus permitting only about .006 inch per hour of storm water to come in from the 1,327 acres of Cambridge lying up stream from the Binney Street district; and, as shown in the foregoing table, almost no storm water can be mingled with the sewage in some of the smaller districts before their regulator gates will shut out all of their sewage and storm water, by reason of the excess of storm water taken into the metropolitan sewer from other districts.

Inspections of Regulator Gates and Overflows during Rain Storms.

During July, August and September, before the new clock gauges were ready, I tried to learn if the action of the various regulator gates on districts tributary to the Charles was normal, and fairly comparable with the indications of the Binney Street, Bath Street and Charles River sewer clock charts already described, by a systematic inspection at each man-hole, immediately after each storm.

Levels were run to establish benches for measuring height of gate and height of water, and an inspection was made by my assistants of the mechanical condition of about 50 of the regulator gates (it was a dirty job), in order to see if pollution was likely to be increased by the gates frequently getting out of order. The results of this inspection were very reassuring. Not one of the regulator gates inspected showed signs of serious derangement.

It was found that showers at times convenient for direct measurement were remarkably few, and that, notwithstanding routes had been planned and the members of our corps of assistant engineers specially detailed to hasten to these whenever rainfall occurred, we rarely found the overflows in action at the moment of inspection; and, although we found two or three very foul discharges, the general effect was to encourage an idea that the periods of overflow were brief, and the discharge seldom noteworthy. The results do not warrant any extended description, and they do not discredit the indications of the clock gauges; on the contrary, they prove the great practical superiority of the clock gauge method to the storm inspection method.

Relation of Sewage Overflow Measured at Binney Street to the Overflow from Other Districts.

This relation must be considered from two points of view: first, the relative duration of overflow in the same storm; second, the per cent. of the sewage being produced meanwhile which is thrown out into the Charles and its tributaries.

Comparative Duration of Period of Overflow. — Data: We have direct measurements of period of overflow by clock gauges for several years in sewers at Bath Street, Lowell Street and Massachusetts Avenue, Cambridge, and by means of the clock gauge in the Charles River valley sewer near Huntington Avenue its period of overflow can be inferred.

The excellent observations on storm flood waves in sewers, made by Mr. L. M. Hastings, city engineer of Cambridge, in 1900, on two different but typical suburban districts of 56 acres and 68 acres, are of great value in this connection for showing how brief the flood period is in small simple drainage districts. In these the duration of the flood wave seldom exceeds the duration of the rainfall by more than half an hour.

New Clock Gauges in Sewers. — For further data in September, 1902, I had clock gauges set at the sewer overflows at Hereford Street and St. Mary's Street, Boston, both of which had been particularly referred to in the evidence as rejecting large quantities of sewage (see evidence, pp. 69 and 296); and I also set a clock gauge on the Stony Brook main sewer at Ruggles and Cabot streets.

I did not get so many comparisons between the Binney Street and Lowell Street gauges and our new gauges at the St. Mary's, Hereford and Ruggles Street regulators as I had hoped for, because the months of October and November, 1902, presented remarkably few rain storms. Our new clock gauge at Ruggles and Cabot streets never worked well, and the surrounding complication of sewer connections perhaps tended to erratic movements of the sewage and the storm water at this location.

Taking the long term series of observations, after carefully revising the records and supplying omissions, the following results are obtained: —

Comparisons of Duration of Periods of Sewage Overflow from Binney Street, Lowell Street, Bath Street and Massachusetts Avenue Districts.

Date of Storm. 1900.	Depth of rain in storms that caused overflow (inches).	Total duration of rain storms that caused overflow (hours).	Binney Street (698 acres). — Hours discharge into Charles. — From regulator and tide gate charts.	Bath Street (215 acres). — Hours discharge into Charles. — From tide gate closure and rainfall chart.	Flood Wave Period observed by Clock Gauges in certain other Sewers in Cambridge for same Storms. Sherman Street district (68.1 acres). Hours.	Shepard Street district (56.5 acres). Hours.	Fifth Street district (10 acres). Hours.	Massachusetts Avenue regulator. — Alewife Brook system (65.5 acres). Hours.
May 3,	2.20	9.0	18.0(?)	11.0	9.2	9.7	–	(11.0)?
9,	.22	2.7	–	–	–	–	–	–
15,	.25	1.0	–	.9	–	–	–	1.8
18,	1.80	24.4	22.5	8.8	–	–	–	21.0
21,	–	–	–	–	–	–	–	(0.0)?
June 3,	.68	14.5	3.2	2.8	–	–	–	10.4
22,	.95	15.2	12.0	12.7	–	–	–	7.5
29,	.45	8.2	–	3.3	–	–	–	–
July 12,	.56	2.6	–	3.3	–	–	–	4.0
18,	.20	.2	–	2.0	–	–	–	.6
25,	1.40	23.0	21.2	28.3	–	–	–	8.7
Aug. 10,	.50	.2	2.4	(5.5)	.6	.7	.5	1.8
13,	.22	1.0	–	1.0	–	–	–	1.7
15,	.20	1.0	–	–	–	–	–	–
16,	1.25	5.0	(11.0)	7.3	–	–	–	3.6
27,	.50	.2	7.0	7.3	.5	.7	.5	2.2
Sept. 16,	1.27	10.0	(7.8)	12.2	–	–	–	(12.0)
17,	2.10	14.6	14.6	11.3	5.5	7.0	–	9.0
21,	.54	4.0	5.6	11.4	1.5	1.6	–	3.4

Comparisons of Duration of Periods of Sewage Overflow from Binney Street, Lowell Street, Bath Street and Massachusetts Avenue Districts — Concluded.

DATE OF STORM. 1900.	Depth of rain in storms that caused overflow (inches).	Total duration of rain storms that caused overflow (hours).	Binney Street (698 acres). Hours discharge into Charles. From regulator and tide gate charts.	Bath Street (215 acres). Hours discharge into Charles. From tide gate closure and rainfall chart.	FLOOD WAVE PERIOD OBSERVED BY CLOCK GAUGES IN CERTAIN OTHER SEWERS IN CAMBRIDGE FOR SAME STORMS. Sherman Street district (68.1 acres). Hours.	Shepard Street district (56.5 acres). Hours.	Fifth Street district (10 acres). Hours.	Massachusetts Avenue regulator. Alewife Brook system (65.5 acres). Hours.
Oct. 8,	1.90	30.3	23.5	26.7	-	-	-	24.0
10,	.23	5.7	-	4.0	-	-	-	(4.0)?
11,	.12	3.0	-	-	-	-	-	-
14,	.45	11.0	6.0	7.0	-	-	-	3.3
28,	.40	4.5	-	3.8	-	-	-	3.7
Total for six months,	-	191.3	154.8	171.2	-	-	-	133.7

A Few Additional Comparisons, — Shepard and Sherman Streets, — Outside of the Six Warm Months, May to October.

Feb. 12,	1.75	14.0	-	-	-	11.0	-	-
22,	2.10	14.0	-	-	-	14.0	-	-
25,	1.35	8.0	-	-	-	9.0	-	-
Mar. 16,	1.20	4.0	-	-	-	7.0	-	-
Nov. 8,	.40	1.0	-	-	2.0	2.0	-	-
24,	.85	8.0	-	-	-	8.0	-	-
26,	1.60	13.0	-	-	-	13.0	-	-

Comparison of Duration of Sewage Overflow in Different Districts, Oct. 5 to Nov. 26, 1902.

Date of Storm. 1902.	Duration of Storm (Hours).	Approximate Mean Depth of Rainfall (Inches).	Hours Duration of Overflow into Charles.				
			Binney Street.	Lowell Street.	Hereford Street.	St. Mary's Street.	
Oct. 1,	9.5*	.45*	(9.0)	0†	10.0	10.5	
Oct. 5,	4.0	.40	4.5	0†	5.0?‡	6.0?§	Tide gate clocks at Hereford and St. Mary's streets not working well.
Oct. 12,	11.0	1.16	11.5	4	14.0?	16.0?	
Oct. 23,	4.0	.22	0	0	.5	1.5	
Oct. 28,	11.5	1.80	14.0	6?	14.0	17.0	
Nov. 26,	8.0	1.00	11.0	6	(8.0)	(8.0)	
Total,	48.0	5.03	49.0	16	51.5	59.0	

Values in parentheses given by interpolation.
* After excluding first six hours in which only 0.10 inch of rain fell, also last 4 hours in which only 0.05 inch fell.
† Tide gate shut throughout.
‡ Not fully closed; partly closed four hours; probably overflowing.
§ Not fully closed.

NOTE. — The Hereford Street has been observed to overflow with small rains. It can at best when regulator is wide open only deliver to the main drainage the flow of a long twelve-inch pipe under about three feet head.

A study in detail of the diagrams from these sewer clocks in certain typical storms gives a much better comparison than the few figures presented above.

Gauge Records from Charles River Valley Sewer. — A study of the year's daily record in form of a continuous diagram from the clock gauge on the Charles River valley sewer is also of especial interest in these comparisons of duration of flood wave period, and exhibits other interesting features, among which are the following: —

The depth is found to be much greater in the spring * than in midsummer, due doubtless to the smaller ground-water yield. This tends toward more vacant space in the sewer for storm water during the summer months, and therefore more room for storm water and a less discharge of sewage into the Charles during the season when it would be most likely to give offence.

* The measurements and estimates of the chief engineer of metropolitan sewers disclose similar variations, probably due to ground water, in the flow of sewage from Cambridge. This in February, 1901, averaged 144 gallons per capita, and in the extremely dry season of August, 1900, only 85 gallons per capita. We do not understand that either of these measurements was very precise.

The average conditions are shown by the following figures: —

Variations in Dry-weather Flow, Charles River Valley Sewer.	Depth in Sewer of Clock Gauge (Feet).	Corresponding Flow (Cubic Feet per Second).
Seasonal Changes.		
June, July, August and September, 24 hours mean,	2.20	-
May (nearly 25 per cent. deeper), 24 hours mean, .	2.70	-
April (nearly 50 per cent. deeper), 24 hours mean, .	3.20	-
Diurnal Changes in Summer.		
Maximum conditions, 10 A.M. to 7 P.M., . . .	2.40	-
Minimum conditions, 3 A.M. to 6.30 A.M., . . .	1.80	-

The great length of this Charles River valley sewer tends to smooth out these diurnal changes, for the maximum flow of sewage from Waltham does not reach the gauge until well toward the time for minimum flow from the Boston and Brighton districts.

The ground-water variation in this sewer as a whole is lessened by the fact that the Newton sewers are under-drained, and discharge this ground water directly to tributaries of the river.

As elsewhere noted, these Charles River valley sewer records show a good many "flood-wave" periods for which there is no precedent rainfall, and which coincide with the high-water period in a way that suggests an occasional leak at a tide gate; and following many storms they show an abnormally long period before the flood wave subsides.

For example: —

Date.	Rainfall (Inches).	Duration of Rainfall.	Time of Flood Wave passing Gauge near Outlet of Charles Valley Sewer.
June 13, 1902, ...	.31	Mostly in 1 hour.	Fully 6.0 hours.
June 15, 1902, ...	.11	All in 1 hour.	Fully 4.5 hours.
June 27, 1902, ...	.33	Mostly in 2 hours.	Fully 13.0 hours.
July 15, 1902, ...	.76	Mostly in 3 hours.	Fully 8.0 hours.
July 20, 1902, ...	.74	Mostly in 2 hours.	Fully 8.0 hours.
Aug. 6, 1902, ...	.23	Mostly in 2 hours.	Fully 11.0 hours.
Aug. 11, 1902, ...	1.12	Mostly in 4 hours.	Fully 13.0 hours.

The time of flood wave given above is doubtless much longer than the period of sewage rejection; but this long duration indicates that in a given storm the period of rejection and overflow of sewage will be much longer at those overflows, located near the down-stream end of a long trunk sewer, as the Charles valley, than for overflows on small districts or near the head of the trunk line, like those near head of Stony Brook conduits.

The actual duration of the flood wave in passing, *with depth sufficient to indicate an overflow* at such localities as St. Mary's Street and elsewhere on the lower part of this long sewer is from three to five hours longer than the duration of the fairly heavy portion of the rain which caused it; but, on the whole, as stated above, this district does not show very much excess in duration of overflows above Binney and Bath Street. The elevation of these overflows, together with the large storage capacity in the common sewers, permits a restraint of the discharge of pollution into the Charles from these overflows all along the Boston side similar to that found at Binney Street.

Percentage of Sewage rejected during Period of Overflow.

As already stated, only a part of all the sewage entering the common sewers from house drains and factories is rejected during the period of overflow. All through the period of rejection the metropolitan sewers are flowing nearly full of mingled sewage and storm water and carrying it out to sea, and all of the sewage in this mixture must evidently be deducted from the total volume of sewage before determining the quantity that pollutes the Charles River.

The data required for determining the percentage of sewage rejected from a given district during the period of overflow are: —

1. The volume of sewage flowing in cubic feet per second or equivalent terms giving rate of flow.
2. The volume of storm water run-off, in cubic feet per second or equivalent terms.
3. The carrying capacity of the channel (as adjusted) through which the mingled storm water and sewage is admitted to the metropolitan or intercepting sewer.

Some very puzzling questions arise if it is attempted to analyze these items minutely for each individual district. If a gate is shut tight evidently 100 per cent. of the mingled storm water and sewage from its drainage area must be rejected during all of the time that it is shut, and we have seen (p. 165) that there are some districts at which the water entering the metropolitan from above will hold this particular gate shut all through the storm. Where a gate is partly shut our data does not give the proportion. We can, however, get this quantity in a general way from a knowledge of the surplus capacity in the metropolitan sewer at this point, available for storm water.

We will next proceed to collect the data on quantity of sewage, per cent. of run-off and capacity of sewers called for above.

Data on the Ordinary Amount of Sewage Flow in the Metropolitan District.

The volume of so-called sewage is found to contain a large quantity of ground water in dry weather. In the wet months it is not far from one-half ground water. The chief engineer of the metropolitan sewers has made estimates relative to this, from time to time, based on depths measured in the sewers at various points, on the delivery of the sewage pumps, the water consumption, and on the population.

His latest estimate, made in February, 1901, was as follows, and the last previous estimate for the midsummer season is given on the next page: —

Winter Flow of Sewage from Various Communities in the Charles River Water-shed.

February 19-22, 1902 (no Rain or Snow Fall in Previous Two Weeks).	All of Cambridge.	Whole North Metropolitan System.	Waltham.	Newton.	Watertown.	Brookline.	Brighton.	For Part of Boston connected Charles River Valley System.	For Whole Charles River System.
Discharge (cubic feet per second),	20.3	68.9	2.8	3.2	1.6	4.0	6.3	5.3	23.2
Gallons (per twenty-four hours),	13,114,000	44,509,000	1,810,000	2,070,000	1,030,000	2,590,000	4,070,000	3,430,000	15,000,000
Miles of local sewer,	110.80	459.97	38.12*	88.30	29.18	49.15	49.12	20.10	273.97
Gross population,	93,700	432,400	23,600*	35,700	9,300	20,200	19,500	16,500	122,800
Connected population,	90,912	303,454	20,538*	22,127	6,477	16,000	12,540	15,720	93,402
Water consumption,	7,965,000	46,139,000	1,770,000	2,290,000	1,050,000	1,840,000	2,220,000	1,860,000	11,010,000
Gallons per capita:—									
Sewage, gross population,	140	103	77	61†	111	128	209	208	121
Sewage, connected population,	144	147	88	94	160	162	324	218	161
Water, gross population,	85	107	75	68	113	91	113	113	90

* From twelfth annual report, Metropolitan Sewerage Commission. † Sewers underdrained.

From the following table it will be noted that during the dry months the flow is much less than in winter. In using the tables immediately above and below it is to be understood that the measurement of the subdivision of the sewage between the several communities is not very precise.

Summer Flow of Sewage from Various Communities in the Charles River Water-shed in Driest Part of a Season of Extreme Drought.

As measured on August 14, 15, 17, 1902. Previous Rain, August 13–14, 0.34 Inch; August 15, 0.39 Inch.

	All of Cambridge.	Whole North Metropolitan System.	Waltham.	Newton.	Watertown.	Brookline.	Brighton.	Part of Boston connected Charles River Valley System.	Whole Charles River System.
Discharge (cubic feet per second),	12.4	55.5	2.3	4.1	1.6	3.6	5.2	3.7	20.5
Gallons (per twenty-four hours),	8,010,000	35,875,000	1,490,000	2,640,000	1,030,000	2,330,000	3,360,000	2,380,000	13,230,000
Miles of local sewer,	70.90	436.89	39.81	84.96	23.50	48.00	47.19	16.90	260.36
Gross population,	93,700	432,700	23,600	33,700	9,300	20,200	19,500	16,500	122,800
Connected population,	90,100	301,730	14,448	18,881	5,525	13,451	12,454	10,688	73,447
Water consumption,	8,245,600	45,535,600	1,820,000	2,020,000	1,020,000	1,590,000	2,140,000	1,700,000	10,290,000
Gallons per capita: —									
Sewage, gross population,	85	83	63	79	113	115	173	144	109
Sewage, connected population,	88	119	103	140	187	173	269	223	181
Water, gross population,	88	105	77	60	110	79	110	110	84

For the Boston West Side Intercepter, draining the district adjacent to the Charles, it is probable that the per capita flow of ground water and sewage is not far from 200 gallons per day in the dry months; and for Stony Brook district not far from 205 gallons, according to measured depths in dry weather and our own estimates.

The general average of the dry-weather flow of sewage and ground-water flow at the present time for the entire sewered area tributary to the Charles, stated in terms easily comparable with the rainfall records, or in equivalent depth in inches per hour, is probably somewhere near .01 inch per hour; and, speaking broadly, the surplus sewer capacity in the sewers above this level of dry-weather flow available for extra flow in time of storm, as found by sundry computations, for the districts tributary to the Charles, is also about .01 inch per hour.

Relation of Run-off to Rainfall.

From lack of data the total immediate run-off has often been assumed at one-half of the rainfall, but it is now proper to inquire briefly as to the accuracy of this assumption.

Probably under average conditions, a depth of from 0.10 to 0.15 inch of rainfall would be soaked up by the lawns, porous street surfaces, etc., or cared for by storage in sewer. The clock gauges at Binney Street and elsewhere have shown this, and it is found that a rainfall smaller than 0.2 inch total depth does not bring the overflows into action, except in the case of a few overloaded sewers in which overflow is sometimes caused by a rapid shower of only 0.10 inch total depth.

For the purpose of considering relation of the immediate run-off to the rainfall, we may regard the rainfall as subdivided into: —

First. — The portion withheld: —

(*a*) Withheld in wetting impervious surfaces, as roofs and asphalt, and all subsequently evaporated. This perhaps amounts to .01 to .02 inch in depth on the area occupied by these impervious surfaces, and will doubtless be nearly constant for all rain storms. Ordinarily this absorbs a very small part of the whole rainfall.

(*b*) Withheld at the porous surfaces, to a small degree on brick pavement and macadam, to a large degree on turf and sandy areas, much of this being subsequently evaporated, though some may go to the ground water. Obviously, this is what becomes of most of the water in those small rains of a total depth of 0.1 inch to 0.15 inch, which seldom appear to affect the depth in the sewer.

(*c*) The space in the large combined sewers, between the dry-weather level and the level where floats close the gates, can care for an appreciable quantity which runs down the sewer after the storm is over.

Second. — The run-off: —

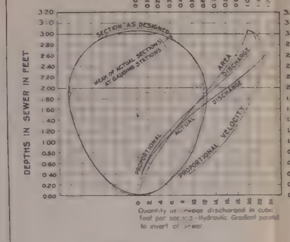
(*d*) From the bare, impervious areas of roofs and asphalt pavements, also from granite block pavements and from well-compacted macadam, from paved yards and from bare, frozen ground; commonly, from well-drained urban districts this water will immediately run through the roof drain or gutter, and be inside the sewer within five or ten minutes.

(*e*) From the porous or sponge-like areas of turf underlaid by clay subsoil, which are soon saturated in a heavy rain, and therefore, if sloping, will shed water rapidly after say half an inch in depth has fallen.

(*f*) From the porous areas with pervious subsoil, which can continuously drink in water at a rate dependent on its degree of porosity and continue to absorb this at a nearly constant rate so long as the rain continues. A porous area would abstract a great deal larger proportion of the total rainfall in a slow, long-continued rain, than in a quick shower yielding the same total depth. On the slope and smoothness of the surface as well as on the porosity of the soil will depend the ratio of the run-off to the absorption on ground of this kind; and when soil containing some small admixture of clay or loam has been baked by drought it apparently absorbs water much less rapidly than after being well softened by moisture.

CAMBRIDGE, MASS., OBSERVATIONS ON RELATION OF RUN OFF IN SEWERS TO RAINFALL

Observations under the supervision of Lewis M. Hastings, C.E. Computations by J.R. Freeman, C.E. F.H. Carter C.E. Principal Assistant on Observations and Computations.



Quantity of sewage discharged in cubic feet per second - Hydraulic Gradient parallel to invert of sewer.

SHEPARD ST. SEWER

HYDRAULIC ELEMENTS AND CURVE OF DISCHARGE OF SEWER between Gauging Station at Walker St. and Gauging Station below in the direction of Beacon Street

DESCRIPTION OF SEWER BETWEEN GAUGING STATIONS

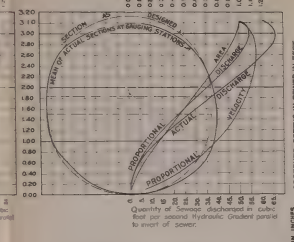
Distance between gauging stations	313 feet
Size of sewer (see sketch above) Brick	28 inches × 30½ inches
Area of cross section of sewer	5.73 sq. ft.
Wetted perimeter of section	8.63 feet
Hydraulic Mean Radius of full section	0.664 feet
Slope of sewer in 100 feet	0.211
or 1 foot in	475
Total fall of invert between stations	0.66 feet
Velocity of water in full sewer with Hydraulic Gradient parallel to invert of sewer.	4.05 ft p.s.
Total discharge of sewer running full with the Hydraulic Gradient parallel to invert cubic feet per second	23.2
Kutters Formula n = .013	

CHARACTERISTICS OF DRAINAGE AREA.

Area tributary to the sewer at Walker St.	86.5 Acres
Percentage of this in Roof Area	12
Percentage of this in Streets	24
Percentage of this in Lawns and gardens	64
Total number of houses	186
Houses from which roof water runs directly into sewer	90
General slope of drainage area	28 feet in 1000
General characteristics of soil	Sandy

LEGEND

—— Depth of Water in Sewer at Upper Manhole at Walker St. and Runoff curves for Shepard Street.
— — Depth of Water in Sewer at Lower Manhole
- - - Rainfall at Cambridge City Hall.
- —— Rainfall at Harvard Observatory



Quantity of Sewage discharged in cubic feet per second Hydraulic Gradient parallel to invert of sewer.

SHERMAN ST. SEWER

HYDRAULIC ELEMENTS AND CURVE OF DISCHARGE OF SEWER between Gauging Station at Walden St. and Gauging Station below in the direction of Rindge Ave

DESCRIPTION OF SEWER BETWEEN GAUGING STATIONS.

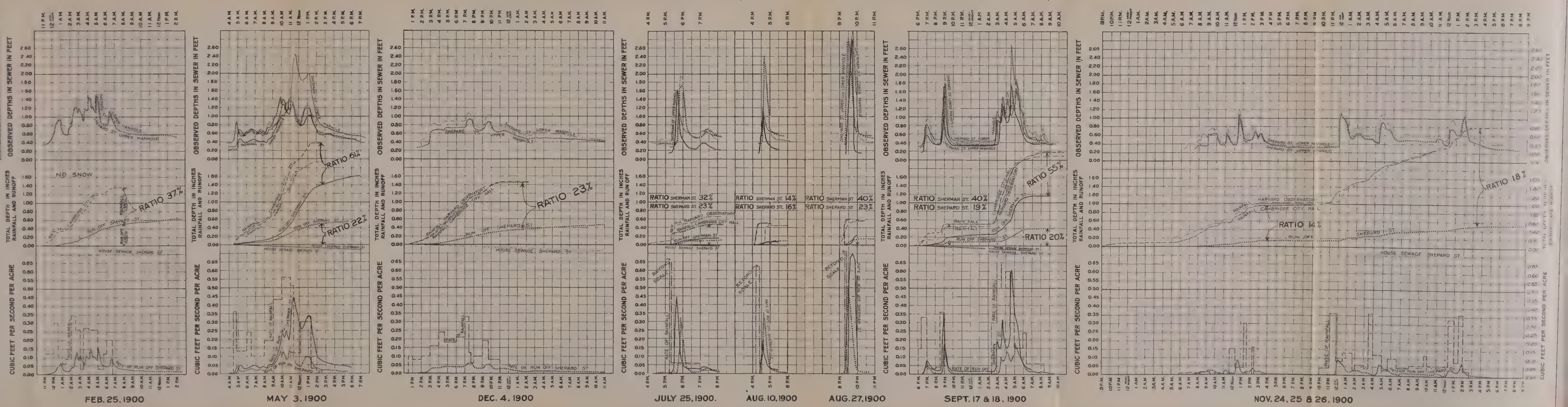
Distance between gauging stations	666 feet
Size of sewer (see sketch above) Brick	36 inches × 40 inches
Area of cross section of sewer	7.82 sq. ft.
Wetted perimeter of section	10.03 feet
Hydraulic Mean Radius of full section	0.780
Slope of sewer in 100 feet	0.605
or 1 foot in	166
Total fall of invert between stations	4.03
Velocity of water in full sewer with Hydraulic Gradient parallel to invert of sewer	7.76
Total discharge of sewer running full with the Hydraulic Gradient parallel to invert cubic feet per second	60.2
Kutters Formula n = .013	

CHARACTERISTICS OF DRAINAGE AREA

Area tributary to the sewer at Walden St.	80.1 Acres
Percentage of this in Roof Area	10
Percentage of this in Streets	18
Percentage of this in Yards and unimproved land	72
Total number of houses	252
Houses from which roof water runs directly into sewer	87
General slope of drainage area	32 feet in 1000
General characteristics of soil	Clay

LEGEND

—— Depth of Water in Sewer at Upper Manhole at Walden St. and Runoff curves for Sherman Street.
- - Depth of Water in Sewer at Lower Manhole



TYPICAL OF ABOUT 8 HOURS STEADY HEAVY RAIN. — TYPICAL BRIEF HEAVY SUMMER SHOWERS — TYPICAL OF STEADY HEAVY RAINFALLS ON GROUND SATURATED BY A PREVIOUS RAINFALL.

The water absorbed into the interstices of the ground will be very slow in reaching the sewer. The rate of percolation is smaller than commonly supposed. It is probably rare that sand will be found in this territory so loose as to permit a movement more rapid than 10 feet per day, and in clay the rate of percolation is extremely slow. Some of the Lawrence experiments of filtration show a motion of water passing through clay of only 5 feet in a year.

And almost the only water that will ordinarily go to form the flood wave in summer, in this territory now in question, is that which falls on and is rejected by the comparatively impervious surfaces of streets and roofs and paved yards.

After considering the above it is obvious that no such simple ratio as one-half can fit with precision all conditions of soil, slope and surface; and the possibility of tolerable accuracy lies in the fact that in general about 20 or 25 per cent. of an urban area is occupied by streets, and that streets commonly present impervious surfaces which quickly drain; and that, out of the remaining 75 per cent. of area in such territory as we now have to consider, from 10 per cent. in the semi-urban districts to 50 or 60 per cent. in the thickly settled parts of old Boston is covered by roofs or impervious yards. Thus the total impervious area runs anywhere from about 25 per cent. to 75 per cent., as will be seen on inspecting the columns giving this in the next table following.

There are few actual measurements on record that give the actual per cent. of run-off during storms or immediately afterward, and how scant the measurements are, on which the assumption was founded that run-off during a storm is one-half the rainfall, is well set forth in a paper by Mr. Emil Knichling, "Transactions American Society Civil Engineers," 1889, vol. 20, p. 3. This assumption appears to have come mainly from a very few measurements made in two London sewers, forty years ago, and from repetitions of a quotation from an early English authority on sewer design over and over again in various books and papers.

The attention of engineers has been focussed more particularly on the peak of the flood wave, or the greatest concentration of water coming at any one moment, for it is this which governs the size of the combined sewer or drain. The few observations on storm flow in sewers reported in the American engineering periodicals refer mainly to the peak of the flood wave.

The Cambridge Sewer Flood Wave Observations of 1900. — The most complete observations on storm flow in sewers of which I have been able to learn are those by Mr. L. M. Hastings, city engineer of Cambridge, undertaken in 1900, at the suggestion of Mr. Howard Carson, C.E., as a part of Mr. Hastings's study for the new system of storm drainage and separate sewers now under construction in Cambridge. These flood wave observations have not yet been worked up, but Mr. Hastings generously placed the data in my hands for computation, and the results for a few typical storms are given in graphical form in the diagram following this page. It is to be hoped that the observations will be extended to cover other territory having a larger per cent. of roofs and more impervious pavements. It is understood that Mr. Hastings was forced to discontinue work on these observations because of pressure of other work and lack of special appropriation.

These observations have a special value in our present investigations, because they are within the area in question and they furnish the best information that we yet possess concerning the probable extent of sewage rejection from the many small districts in the Stony Brook region and in much of Cambridge. They show that the duration of the flood wave from a small district is only $\frac{1}{4}$ to $\frac{1}{2}$ hour longer than the period

of heavy rain, and is much shorter than the period of rejection for Binney or St. Mary's Street.

These Cambridge flood wave observations in each case consisted of two independent sets of rainfall records on opposite sides of the districts under observation, one set by the continuous recording rain gauge at City Hall, and the other by the continuous recording gauge at Harvard Observatory, Cambridge, also chart records of flow-depth and time, made by two clock gauges set in manholes on the same sewer at considerable distance apart. The curves have been subdivided to ten-minute intervals, and the actual, observed run-off computed from the given hydraulic gradient, the known slope of invert and the observed depth, the measured sectional area, and the Kutter formula, using $n = .013$.

By having two continuous-recording rain gauges on opposite sides of the district and by having two independent continuous-recording depth gauges in each sewer, the records by these instruments are rendered certain beyond question; and I am assured by the assistant engineer who conducted the observations that the areas of the drainage districts present little room for doubt, although there are one or two cross-connections through which water might perhaps enter or escape, if the declivity of the sewer at these connecting summits were not, as shown by the records, too steep to permit this.

These summer flood wave experiments show that in the semi-urban Sherman Street district, which has a *clay subsoil* and moderately steep slopes, and has 18 per cent. of street area and 10 per cent. of roof area, a total impervious area of 28 per cent., the proportion of the total rainfall which reaches the sewers during heavy, rapid storms averages only about 50 per cent., and in small or slow storms is much less than 50 per cent. There is much grass land in this Sherman Street district, and, although the clay subsoil is doubtless almost absolutely impervious, the turf and top loam will act like a sponge, and soak up some of the rain.

In a thickly built portion of the city, where the roof area is much larger and many yard areas are paved, the proportion of run-off will doubtless be larger than this 50 per cent. found in the Sherman Street district. On the back side of Beacon Hill, Boston, it may perhaps be 80 per cent. in quick, heavy storms.

In the semi-urban Shepard Street district, which has *an open, sandy* soil, and is nearly level and largely covered with turf, thus affording the very best opportunity for absorption of all of the rain, excepting that which falls on the roof, the sidewalk and the macadam street surface, the per cent. of total run-off during the storm and up to two or three hours after rain had ceased was found to be only about 25 per cent. in the heaviest storms observed, and considerably less than this in gentle rains. In winter, with the ground surface sealed by frost, it would doubtless have been much more.

The comparison stands as follows: —

District.	Per Cent. of Roof Area.	Per Cent. of Street Area.	Subsoil mostly.	Average Declivity (Feet in 1,000).	Actual Average Per Cent. of Run-off in Heavy Storms.
Sherman, ...	10	18	Open sandy.	32	49
Shepard, ...	12	24	Clay.	28	23

I could not credit this great difference in the proportion of run-off from these two contiguous districts until after a personal examination

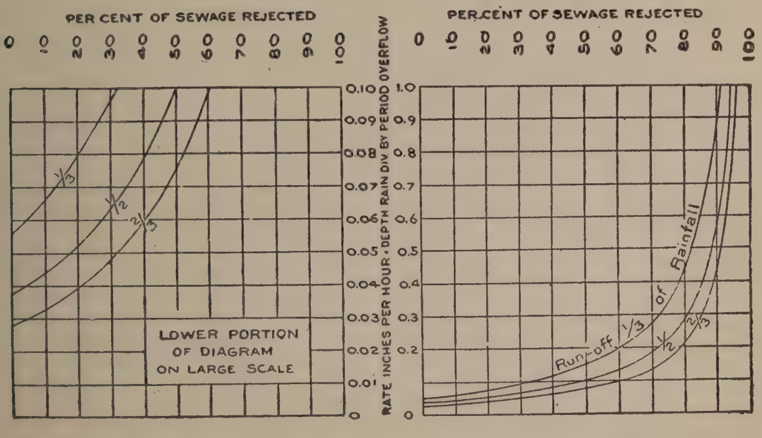
throughout most of their streets. I found the Shepard Street district, which gave the 25 per cent. run-off, flat, with broad areas of grass land; and, on going through the streets of both districts during a gentle rain, it was easy to see a difference in the drainage into the catch-basins, and to see that little water was draining off the surface of the grass land.

From considering broadly the entire 14,000 acres of sewered territory tributary to the Charles in the light of the percentages of impervious roof and street surface shown in the large table next following, I think it probable that the average immediate run-off in rain storms of more than 0.20 inches total depth will be found somewhere between 25 and 50 per cent. of the total rainfall, because the area with closely built impervious surface and impervious sub-soil is relatively small; from such information as is available, and from lack of better, I assume that 40 per cent. will be not far from correct as an average value for all districts, and for all storms, gentle and heavy, which produce overflow in the summer months.

Method of computing the Percentage of Sewage discharged into the Charles River during the Hours of Overflow.

At Binney Street, the next to the last column in table on p. 161 was computed by first taking a separate record of each storm, and finding the rate of rainfall; for this purpose the total depth of rainfall was divided by total hours duration of rain. The assumption was then made that the ratio of the run-off to the rainfall was 50 per cent. for the Binney Street district. The larger the ratio assumed, the larger will be the computed quantity of sewage rejected.

The regulator gate record shows that the closing was continuous, and it appeared proper to simplify computation by adopting a mean value for the rate of rainfall during the entire period of rejection. The rejection does not begin with Binney Street until half an hour after the rain, or in slight rains, or when tide is high, rejection may begin very much later. On the other hand, it continues some hours after rain has ceased. So this rate used was not strictly the rate at which the rain fell, but rather the average rate at which it reached the regulator gate. The per cent. rejected was then found by means of the following diagram.



BINNEY ST REGULATOR PER CENT OF SEWAGE PROBABLY REJECTED DURING VARIOUS RATES OF RAINFALL

The data used in computing this diagram was that specially applicable to Binney Street, and was as follows: —

	Cubic feet per second.
Ordinary dry weather flow of sewage and ground water, .	9
Capacity of sewer to receive inflow from Binney Street, .	22

The computation for the diagram was then simple, viz.: —

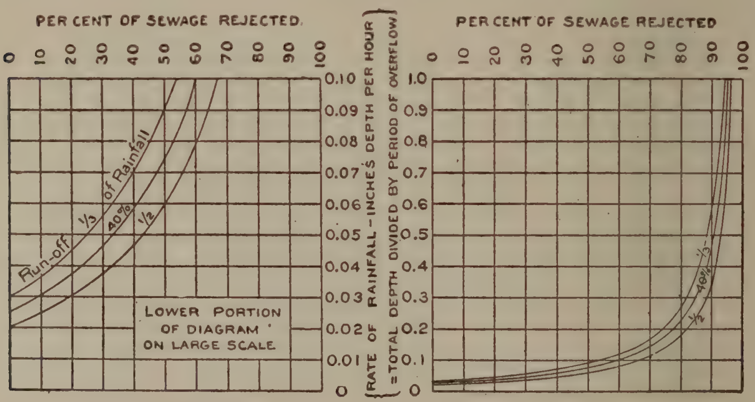
	Cubic feet per second.
For a rainfall of .20 inches per hour, equivalent, on 698 acres tributary to sewer, to	142
Run-off assumed at one-half rainfall, ...	71
Mean rate dry-weather flow sewage and ground water, . .	9
Total storm water plus sewage, ...	80
Total that metropolitan can receive, ...	22
Total that metropolitan must reject, ...	58
Per cent. of mixture and of each ingredient rejected, . .	72

Per Cent. of Sewage rejected during Overflow in Other Districts. — For the average district somewhat different proportions were adopted, because Binney Street district is favored by so adjusting the gate that it can receive nearly twice as large a proportion of storm water as most others.

It may prove more convenient for computation to measure the rates of rainfall, run-off, sewage flow and sewer capacity all in the equivalents of inches per hour in depth from the area drained, instead of in cubic feet per second.

For the average case, sewage and ground water were taken equivalent to a depth over the entire area sewered of .01 inch per hour. The surplus capacity in sewer available was taken also at .01 inch per hour, or just about double the dry-weather flow. The ratio of run-off was taken at 40 per cent., and the computation for the following diagram made substantially as before.

It will be noted that, for the average storm, with rainfall of 0.1 inch per hour, while the rejection by the Binney Street diagram will be 50 per cent., the rejection by the following diagram would be about 60 per cent. of the entire sewage flow for the time being.



REGULATOR GATE ADMITTING TO INTERCEPTING SEWER

PER CENT OF SEWAGE REJECTED WITH VARIOUS RATES OF RAINFALLS

For Sewers in which Dry Weather Flow occupies about one half of Capacity of Sewer and Storm Water is equivalent to Run-off of 0.1 inch Depth per Hour from Tributary Watershed

Reviewing these various cases of actual measurement of period of sewer overflow in more detail, we may note that at Binney Street, with its low elevation, the tide often holds back the overflow until it has had time to escape down the sewer, and thus cuts off 56 hours from the average annual total of 189 hours' sewage rejection, reducing the total time of overflow from 4.3 per cent. to 2.8 per cent. of the total time.

In a similar way, the holding of the water level of the future basin all of the time at grade 8 will tend to lessen the period of sewage overflow very materially.

Summary of Measurements upon Sewage Overflow into Charles River.

We fortunately have observations upon the sewer systems which present the extreme conditions of greatest and least overflow. The Charles River valley, Binney Street and Bath Street represent the large districts, with long sewers and longest duration of overflow; Massachusetts Avenue, Cambridge, and Lowell Street represent intermediate conditions; and the Hastings flood wave experiments give excellent data on the period of overflow from small, short districts like the many small districts up Stony Brook.

The rainfall records also serve to fix the possible limits in a general way.

St. Mary's, Hereford and Charles River Valley. — The lower end of the Charles River valley sewer doubtless now presents the conditions giving the longest period of overflow. The gauge charts indicate this, and the conditions which cause it are plain, — the long sewer, the brook drainage and ground water reported taken in at Brighton and Brookline, and the overloaded condition of the main drainage conduit into which it discharges. But, notwithstanding these adverse conditions and the fact that it may be sometimes swamped by the full intake from the Church Street, Dedham and Dover Street districts, its duration of its overflow during our observations was but little longer than from Binney Street, but its per cent. of sewage rejected during this time may be somewhat higher. From the few comparisons in the same storms, considerations of tidal interference and by analogy with the four years observations on Binney Street, it appears probable that the quantity rejected here cannot exceed the proportion measured as rejected at Binney Street by more than 50 per cent., which would give 3 per cent. of total quantity as rejected and discharged into the Charles. It does not appear possible that the Charles River valley sewer as a whole can now overflow more than 6 per cent. of the time during the six warm months, and not possible that more than 75 per cent. of the sewage is thrown out during this 6 per cent. of time, thus giving at most a total rejection of 4 per cent. of the sewage under present conditions.

So soon as the new high-level sewer is connected, and before the proposed dam can possibly be built, conditions will be so changed that the separate system sewage from Newton, Waltham and Watertown can no longer be crowded out into the Charles by storm water from below, and a larger per cent. of flood water can be taken in, because of extra pumps which its metropolitan commissioners already propose to install. Fifty thousand population will cease to contribute to this overflow, and for the remaining 50,000 the conditions of sewage rejection can surely not be very much worse than those found for Binney Street during the past four years; and we shall surely not have during the six warm months more than 3 per cent. of all their sewage thrown into the Charles. (This 3 per cent. is double that actually found at Binney Street.)

Conditions in the Charles River valley sewage rejection are sure to

improve in the more distant future, as the separate system of sewage becomes extended in Brighton, Brookline and the Back Bay and Roxbury districts, and the parts of Boston tributary to this system. The improvement from separation of storm water from sewage will surely more than offset the effect of growth in population.

Binney Street District. — On p. 161 it has been shown that under the conditions existing in the six warm months during the past four years the actual rejection of sewage shown by the gauges has only been about 1.4 per cent., or, as a maximum, 2.0 per cent., of all the sewage produced by this population of about 82,000.

By the plan of improvement which I propose for maintaining circulation in the Broad and Lechmere canals, all of this sewage overflow will be diverted from the basin.

For reference in studying other districts, the following summary of the Binney Street records is presented: —

Year (for Six Warm Months only).	Total Hours of Rainfall, excluding all Storms of Less than 0.20 Inch Total Depth.	Total Hours of Observed Rejection of Sewage into Charles River.	Additional Hours of Rejection held back by Tide until discharged through Metropolitan.	Total Hours of Closed Regulator.
1899, ...	201	115	33	148
1900, ...	204	155	55	210
1901, ...	205	156	68	224
1902, ...	193	70	68	138
Average of total hours,	201	124	56	180
Ratio to entire time, per cent.,	4.6	2.8	1.3	4.1

Only about 50 per cent. of the sewage during the above time was rejected; the remainder went off through the metropolitan sewer.

Bath Street District. — The tide has little effect in holding back sewage overflow from this district. For it will be noted from the profile at p. 164 that the crest of its overflow sets at an elevation near high tide, and its storage capacity is limited; therefore, although its district is smaller and shorter than the Binney Street, it is not strange that the hours of rejection into the Charles are longer. But it is of special interest to note that they fall short of the total hours of closed regulator at Binney Street; in fact the Bath Street records and the Binney Street records as a whole confirm each other remarkably well, as will be seen by the following comparison: —

Year (for the Six Warm Months only).	Bath Street.	Binney Street.	
	Total Hours of Observed Rejection of Sewage into the Charles River.	Total Hours of Closed Regulator Gate.	Total Hours Rejected into Charles.
1900, ...	171	210	155
1901, ...	177	224	156
Average of total hours, . . .	174	217	156

A total period of sewage discharge of 174 hours in six months is 4.0 per cent. of entire time. There appears to be no reason why the per cent. of sewage rejected should average more than 62 per cent. during this time. This gives 2.5 per cent. as the total proportion of sewage rejected, but for an outside estimate we will call this 3 per cent.

Lowell Street District. — This overflowed only 26 hours during the six warm months of 1902. Its charts show that periods of discharge are brief, and it has some characteristics of the Shepard Street district. This 26 hours of overflow is only 0.6 per cent. of time, but in an average year fully 1 per cent. or perhaps 1.5 per cent. duration of overflow may be expected. The per cent. of rejection during the period of overflow will probably not exceed 50 per cent. So the total discharge into the Charles from this overflow will not exceed 0.75 per cent. or at most say 1 per cent. of the sewage that originates in this district. This clock gauge has been here only during the year 1902, and these six months were exceptional by their few storms of magnitude sufficient for producing overflow.

The area of this Lowell Street district is slightly larger than the Bath Street district, but it is farther out in the suburbs, with less impervious area of roof and pavement, but with fairly rapid delivery of its storm water. It is seldom subject to interference by tide, because of elevation and of small storage capacity. By table on p. 164 it will be noted that it is favored in the adjustment of the regulator floats by the admission of an exceptionally large proportion of storm water, thus lessening the tendency to overflow.

Massachusetts Avenue District, Cambridge. — This district is not tributary to the Charles, but was worked up for purposes of comparison, and as typical perhaps of some other districts.

The area is not large, and of a semi-suburban character and rather flat. The tide seldom or almost never interferes with its overflow.

YEAR (FOR SIX WARM MONTHS ONLY).	Massachusetts Avenue. — Hours of Sewage rejected and Regulator closed.	Binney Street. — Hours of Closed Regulator.	Bath Street. — Hours of Sewage rejected.
1900,	134	210	171
Proportion of entire time,	3 per cent.	-	-

Making allowance for what goes down the metropolitan sewer, it appears probable that the entire proportion of sewage rejected would not exceed 2 per cent.

Shepard Street and Sherman Street. — There was no regulator here, and no overflow or rejection from this immediate district; but the experiments on storm flood waves serve to measure the depth with great accuracy at all times during the storm; and by a study of the diagrams, samples of which are shown at p. 174, one is able to predict the duration of sewage overflow from a similar district, with regulators adjusted as ordinarily found, or with simple weir overflows like those common in the Stony Brook district.

These observations under Mr. Hastings's direction at Shepard Street and Sherman Street are of especial value in showing the short duration of the storm flood wave in a small district with fair drainage slopes.

In general, it is found that for sudden heavy showers the duration of flood wave high enough to cause overflow only exceeds the duration of the shower by about half an hour.

That the several districts might be studied individually and collectively, the following table was prepared, as the result of much research in field and office.

SOURCES OF INFORMATION FOR DATA IN OVERFLOW TABLE, COMPILED BY F. H. CARTER, ASSISTANT ENGINEER.

Overflow.

Type of tide gates from detail plans in office of sewer departments.

Type of regulator nozzle mostly from inspections and measurements by W. E. Spear, C.E., and C. H. Rooks, C.E.

Sizes of regulator nozzle mostly from direct calibration by W. E. Spear, C.E., and C. H. Rooks, C.E.

Type and size of overflow outlet from detail plans in sewer department office.

Elevation of overflow crest mostly from actual levels by C. H. Rooks, C.E., supplemented by an examination of detail plans.

Intercepting Sewer.

Dry-weather flow in Cambridge from our own rough measurements of depth flowing.

Dry-weather flow in Charles River valley from data furnished by chief engineer, metropolitan sewer works.

Dry-weather flow in Stony Brook valley from rough measurements of flow at Cabot and Ruggles streets by Mr. R. W. Armstrong, C.E.; at other points pro rata to population.

Dry-weather flow at west side intercepter from our own rough measurement at Cambridge Street, supplemented by estimate based on information furnished by chief engineer, metropolitan sewerage works.

Computed capacity full and at level of tributary cut-off from our own computations from profiles and detail plans on file at sewer departments.

Tributary Sewer.

Elevation of invert, type and size taken from plans on file in city engineers' offices.

Capacity at full depth by our own computations from the above data.

Water-shed.

House sewerage areas and storm drainage areas, by our own planimeter measurements from plans in city engineers' offices, supplemented by our examination of divides on ground, except in Boston, where, because of lack of time, plans on file were used exclusively.

Percentage street area by our scale measurement and computation from atlas and street plans.

Percentage house area by our count of houses shown on most recent Bromley atlas, except for Brookline, where map of town engineer was used.

Equivalent number of average-size houses from atlas, by counting roof areas of all descriptions, estimating larger roof areas than typical houses as so many times average-size house. (Average-size house for Roxbury and West Roxbury assumed as 1,280 square feet area, all others as 1,000 square feet.)

Probable general character of subsoil in Cambridge, from L. M. Hastings, C.E.; for all other districts by Frederick G. Clapp, instructor in geology at Massachusetts Institute of Technology.

Average general declivity of surface, roughly estimated, from contour maps in city engineers' offices.

Overflows from Boston WEST SIDE INTERCEPTING SEWER *into Charles River.*

Number of Overflow.	OVERFLOW. Location of Overflow.	Type of Tide Gate and Number of Gates.	Regulator Nozzle from Common Sewer. Type.	Regulator Nozzle. Size (to Nearest Inch).	Overflow Channel. Type.	Overflow Channel. Size (to Nearest Inch).	Elevation of Crest of Overflow. Datum, 100 Feet below Boston Base.	Intercepter just below this Inlet. Probable Ordinary Dry-weather Flow (Cubic Feet per Second).	Computed Capacity at Tributary Cut-off Level (Cubic Feet per Second).	Computed Full Capacity (Cubic Feet per Second).	Tributary Sewer. Elevation of Invert of Common Sewer.	Tributary or Common Sewer. Type.	Size (to Nearest Inch).	Computed Carrying Capacity, Sewer Full, Cubic Feet per Second (Nominal).	Water-shed. Area Contributing. House Sewage (Acres).	Storm Drainage (Acres).	Impervious Surface (Per Cent. of Water-shed). Approximate Area Street and Pavement Surface (Per Cent.).	Approximate Equivalent Number of Houses (Average Size).	Approximate Per Cent. of Roof Area.	Probable Formation, Clay or Sandy.	Approximate General Declivity of Surface (Feet per Thousand).	Population. Approximate Total contributing Sewage to Overflow, Jan. 1, 1903.	Corresponding Approximate Population per Acre.	Corresponding Average Number People per House.	Sewage Rejected. Probable Per Cent. of Sewage rejected from this District.*	Equivalent Population continuously contributing Sewage under Present Conditions.	REMARKS.
1	Huntington Ave. and Gainsboro St.,	(See 10)	R	6 x 20	E	36 x 48	104.48	14.6	71	134	104.48	E C	30 x 30 and 15	23	91	125	16	546	10	Sandy,	5	2,970	33	7.0	2.0	57	
2	Beacon and Hereford Sts.,	2 B	R	6 x 19	R	48 x 60	106.63	14.2	26	53	102.55	C	78 x 78	106†	121	121	22	1,530	29	Sandy,	5	6,180	51	4.0	3.5	214	
3	Beacon and Fairfield Sts.,	2 B	R	6 x 19	R	40 x 48	[illegible]	12.4	30	53	101.46	X	72 x 74	[illegible]	[illegible]	[illegible]	25	790	25	Sandy,	5	[illegible]	49	4.5	3.6	108	
4	Beacon and Dartmouth Sts.,	2 B	R	6 x 19(?)	E	36 x 48	104.50	12.9	26	53	108.48	Q	72 x 74	237†	68	68	48	960‡	35	Sandy,	5	2,880	44	2.9	3.5	90	Note larger per cent. street and roof area.
5	Beacon and Berkeley Sts.,	2 B	R	[illegible]	E	48 x 60	[illegible]	12.5	[illegible]	53	[illegible]	[illegible]	[illegible]	[illegible]	90	90	25	2,260	32.5	Sandy,	5	3,220	36	2.5	3.5	113	
6	Beacon and Beaver Sts.,	2 B	N	10	R	48 x 60	106.41	12.1	20	53	100.40	W	48 x 58	53	55	77	25	1,070	22	Sandy,	5	7,800	144	7.4	1.5	118	Public garden area included in storm area.
7	Brimmer and Back Sts.,	2 B	R	6 x 19	R	36 x 48	106.77	11.0	20	53	102.20	E	30 x 54	34	54	101	13	380	14	Clay, 60 per cent., Sandy, 40 per cent.,	5	3,680	68	5.9	2.0	74	Common area included in storm area.
8	Charles and Cambridge Sts. (district regulator),	2 B	U	17	L	42 x 60	105.20	10.5	15	33	103.30± 103.70±	E X	38 x 51 22 x 24	35	92	93	26	1,680	43	Clay, 70 per cent., Sandy, 30 per cent.,	21	21,100	229	12.5	3.0	633	Dry-weather flow at this point includes sewage from population below site of proposed dam. This sewage is rejected below in time of storm.
9	Leverett and Brighton Sts.,	2 B	N	6	C	24	110.14	(6.0)?	–	20	109.59	L	24 x 36	30	This overflows at Craigie Bridge.						–	–	–	‡	–	–	
	Totals and averages (by weight),	–	–	–	–	–	–	–	–	–	–	–	–	–	639	742	25	8,451	26	Sandy, 83 per cent., Clay, 17 per cent.,	7	51,310	88	–	–	1,416	
9a	Continuous overflows into Charles River from Beacon St. houses,	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	830 52,140	–	–	–	830	Continuous overflow.

† Large size intended for storage of flow during high water.

‡ Number of houses includes churches and public buildings.

Overflows from BRIGHTON INTERCEPTER *(Metropolitan), and from* CHARLES RIVER VALLEY *(Metropolitan) Sewer.*

No.	Location of Overflow.	Tide Gates.	Reg. Type.	Reg. Size.	Channel Type.	Channel Size.	Elev. of Crest.	Dry-weather Flow.	Cap. at Cut-off.	Full Cap.	Elev. of Invert.	Trib. Type.	Trib. Size.	Trib. Capacity.	House Sewage (Acres).	Storm Drainage (Acres).	Street (Per Cent.).	Equiv. No. of Houses.	Roof Area (Per Cent.).	Formation.	Declivity.	Population.	Per Acre.	Per House.	Per Cent. Rejected.	Equiv. Population.	Remarks.
10	Huntington Ave. and Bryant St., Boston,	2 B	R	10 x 20	E	36 x 48	104.00	–	72	93	101.04	E C	36 x 48 15	27	–	(See 1)	–	–	–	–	–	–	–	–	–	–	
11	Bryant and Hemenway Sts., Boston,	2 F	N	27	C	20	107.19	(See 1)	(See 1)	(See 1)	104.27	E	30 x 36	21	–	(See 1)	–	–	–	–	–	–	–	–	–	–	
12	Huntington Ave. and Greenleaf St., Boston,	N	N	–	E(?)	36 x 48	104.56	25.2	(48)	93 (48)	108.7±	C	15	3.2	182	182	28	1,000	13	Sandy, 50 per cent., Clay, 50 per cent.,	5	8,030	44	8.1	3.0	243	
13, 14	Huntington Ave. and Parker St., Boston (these are not in use; not overflows in common sense),	2 B	(?)	(?)	–	Same channel as No. 12.	104.63	–	–	–	104.63	(?)	51 x 53	71	–	(See 12)	–	–	–	–	–	–	–	–	–	–	
15	Brookline Ave. and Audubon Road, Boston,	2 B	(?)	(?)	C	18	108.81	22.6	42	56	100.7± 100.8±	(?)	24 x 31 32 x 42 15	11.8 30	215	177	12	290	4	Sandy,	5	1,540	8	5.1	2.0	31	Estimated that storm drainage system takes about 60 per cent. storm water in this district.
16	Commonwealth Ave. and St. Mary's St., Boston,	2 B(?)	R	6 x 20	C	15	110.56	22.1	61	56	103.19	(?)	32 x 42 15	47 3.4	44	0	–	–	–	–	–	50(?)	–	–	3.0	2	
17	Commonwealth Ave. and St. Mary's St., Brookline,	2 B	R	9 x 29	P	84 x 98	108.85	22.1	48	56	–	X	84 x 88	131	1,757	980	19	3,350	7	Sandy, 80 per cent., Clay, 20 per cent.,	24 56 } 36	27,280	16	8.1	13.0	817	Estimated that storm drain in Boston (Muddy River) drainage area drains about 100 acres.
18	Commonwealth Ave. and St. Mary's St., Metropolitan (overflow outlet same as No. 17),	1 F	N	66	P	48 x 60	108.85	22.1	(56)	56	98.45	G	54 x 61 (Intc.)	56	Intc.	Intc.	–	–	–	–	–	–	–	–	–	–	Overflow from intercepter.
19	Salt Creek, Brighton,	2 B(?)	R	9 x 29	(?)	(?)	113.60	15.0	35	40	111.4±	E	38 x 36 30 x 45 24	41 49 3.2	488	130	18	507	11	Sandy, 60 per cent., Clay, 40 per cent.,	15	4,580	10	3.8	2.5	148	
20	Cambridge and Seattle Sts., Brighton,	1 B(?)	R	6 x 20	C	36	105.24	13.5	42	40	107.2	(?)	30 x 36 30 x 30 15 18	14.0 18 2.4 4.5	104	0	–	–	–	–	–	2,800	27	–			
21	Western Ave. and Everett Sts., Brighton,	2 B(?)	R	9 x 30	R	24 x 28	107.88	13.6	30	37	108.5(?) 107.6±	E(?) C E(?)	30 x 46 30 x 39 and 24 36 x 38	22 15 – 26	153	253	17	1,256	11	Sandy(?),	10	4,350	28	3.5	2.5	109	
22	Western Ave. and Market St., Brighton,	2	R	6 x 20	E	30 x 39	106.36	11.2	34	37	107.19 (?)	E E(?)	20 x 30 and 20 x 26	8 46	37	37	21	209	13	Sandy(?),	15	1,340	35	6.4	3.0	40	
23	Muddy River, near Aspinwall St., Brookline,	None.	–	No. reg.	–	–	–	–	(See 17)	(See 17)	–	–	–	–	–	(See 17)	–	–	–	–	–	(See 17)	–	–	–	–	
24	Parson's Brook Culvert, Brighton, overflow from intercepter,	1	N	36	C	48	107.70	–	(27)	37	104.65	G	54 x 61 (Intc.)	37	Intc.	Intc.	–	–	–	–	–	–	–	–	–	–	Overflow from intercepter.
25	No. Beacon St., near B. & A. R.R., Brighton,	2 B	R	9 x 29	R	48 x 48	110.32	10.6	33	37	108.1±	E	30 x 36	47	(309) 361	Sep. 347	from Watertown. 17	1,048	7	Clay, 60 per cent., Sandy, 40 per cent.,	35	5,510	21	5.3	3.5	193	Storm drain with about 6 catch basin connections takes from storm area
26	No. Beacon St., near B. & A. R.R., Brighton,	2 B(?)	–	(See 25)	C	18	110.14	–	33	37	108.0±	(?)	30 x 30	31	–	(See 25)	–	–	–	–	–	(See 25)	–	–	–	–	
27	Parsons St., near No. Beacon St., Brighton,	2 B	R	[illegible]	C	45	110.84	5.0	[illegible]	37	[illegible]	E	[illegible]	103	708	788	6	1,012	3	Clay, 70 per cent., Doubtful, 30 per cent.,	17	4,190	10	4.1	4.0	164	Storm drain with about 30 catch basin connections takes from storm area. Four internal sewer overflows also.
28	Near Faneuil Sts., Brighton,	1 B	C	12	C	36	113.47	7.7	26	37	110.0	E	28 x 42	88	26	26	24	95	8	Clay,	10	390	15	–	4.0	16	
	Brighton — Totals and averages,	–	–	–	–	–	–	–	–	–	–	–	–	–	3,998	2,867	15	7,823	6	Clay, 30 per cent., Sand, 48 per cent., Doubtful, 18 per cent.,	22	60,000	15	–	–	1,788	
29	Maple St., Watertown, from Newton (Hyde Brook),	1 F	–	–	C	12	113.01	7.6	22	30	–	–	–	–	(42)†	–	–	–	–	–	–	–	–	–	–	–	These separate system overflows seldom discharge, but sewage from Newton, Watertown and Waltham is rejected from the Charles River Valley sewer at various points (in Brighton, Brookline and Boston).
30	Maple St. (continuous overflow),	None.	–	–	–	–	114.88	–	–	–	–	C	6	–	480‡ (?)	0 (?)	–	–	–	–	–	24,500	–	–	0§	0	
31	Galen Street, Watertown,	–	–	–	C	10	114.88	4.4	18	30	–	–	–	–	517	0	–	–	–	–	–	7,100	–	–	0§	0	
31a	Watertown St., Watertown,	–	–	–	–	–	–	–	–	22.2	–	–	–	–	57	0	–	–	–	–	–	–	–	–	–	–	
31b	Crescent St., Newton,	–	–	–	–	–	–	–	–	22.2	–	–	–	–	1,156	0	–	–	–	–	–	–	–	–	–	–	
32	Albemarle Road, Newton, at Cheese Cake Brook,	1 F	–	–	C	21	123.28	–	–	24.6	–	–	–	–	(26)† 1,166	0	–	–	–	–	–	–	–	–	–	–	
33	North and Calvary Sts., Waltham (district regulator),	1 F	–	20 x 46	–	–	124.00	2.3	–	24.6	–	–	–	–	384	0	–	–	–	–	–	13,400	–	–	0§	0	Estimate of population of Watertown, Waltham and Newton includes only that connected with sewers.
33a	Calvary St., Waltham,	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
34	Newton St., Waltham,	1 F	–	–	–	–	–	–	–	–	–	–	–	–	780	0	–	–	–	–	–	–	–	–	–	–	
	North Metropolitan — Totals,	–	–	–	–	–	–	–	–	–	–	–	–	–	4,578	–	–	–	–	–	–	45,000	10	–	–	0	Forced out after connection to high level by water from below.

† Tributary to a connection with no overflow.

‡ 36 acres in Watertown.

§ After connection to high level sewer.

Overflows from Common and Intercepting Sewers in STONY BROOK VALLEY, *Boston. (Roxbury and West Roxbury Districts.)*

No.	Location of Overflow.	Tide Gates.	Reg. Type.	Reg. Size.	Channel Type.	Channel Size.	Elev. of Crest.	Dry-weather Flow.	Cap. at Cut-off.	Full Cap.	Elev. of Invert.	Trib. Type.	Trib. Size.	Trib. Capacity.	House Sewage (Acres).	Storm Drainage (Acres).	Street (Per Cent.).	Equiv. No. of Houses.	Roof Area (Per Cent.).	Formation.	Declivity.	Population.	Per Acre.	Per House.	Per Cent. Rejected.	Equiv. Population.	Remarks.
†35	Cabot and Vernon Sts.,	2 B	U	–	E	40 x 50	112.50	30	(38)	73	111.80	C E	15 and 40 x 49	48	383	383	19	2,900	23	Clay, Sandy, 10 per cent.,	13	26,500	69	8.6	4.0	1,060	
†36	Whittier and Hampshire Sts.,	1 B	N	–	E(?)	33 x 36	107.21	–	(38)	73	107.24 106.65	C W	15 and 33 x 36	27	(See 35)	(See 35)	–	–	–	–	–	–	–	–	–	–	
†37	Whittier and Tremont Sts. (north side),	2 B	N	–	R	24 x 36	107.46	30	(38)	73	106.96	E	32 x 46	39	45	45	23	480	30	Sandy,	5	4,870	108	10.6	5.0	243	Storm drain takes about 10 per cent. storm water.
†38	Whittier and Tremont Sts. (south side),	2 B	N	–	(?)	(?) x 33	108.40	30	(38)	73	107.66	E	24 x 30	33±	14	14	31	198	23	Sandy, Clay,	5	1,020	73	5.2	3.0	30	Storm drain takes about 10 per cent. storm water.
†39	Ruggles St. and Rogers Ave.,	2 B	N	–	H	24 x 46	107.08	30	(38)	68	107.10	H	40 x 49	60	48	48	26	201	21	Sandy,	6	3,500	73	11.5	3.0	105	
†40	Elmwood St., near Linden Park,	2 B	N	–	(?)	40 D (?)	113.40	30	(38)	73	111.91	E	39 x 46	33	36	36	25	300	25	Clay,	30	2,150	63	5.7	5.0	108	
40a	Hampshire and Linden Park Sts.(?),	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
41	Tremont St., near Terrace St.,	N	N	–	C	34 x 34	121.50(?)	30	(38)	37	120.7(?)	(?)	24 x 36	33	51	51	25	578	22	Clay,	57	3,390	66	5.9	5.0	169	
	Totals and averages,	–	–	–	–	–	–	–	–	–	–	–	–	–	565	582	21	4,685	23	Clay, 76 per cent., Sandy, 24 per cent.,	10	41,380	74	–	–	1,778	
42	Roxbury Crossing, Columbus Ave. and Tremont St.,	None.	N	–	E	34 x 36	117.00(?)	16.9	–	37	–‡	–‡	–‡	(See 41)	(See 41)	(See 41)	–	–	–	–	–	–	–	–	–	–	
43	Columbus Ave., just beyond Tremont St.,	None.	N	8	C	15	129.6±	16.1	(39)	37	130.8±	E	32 x 40	(?)	45 11	45 11	30 20	480 64	25 16	Clay, Clay,	38 50	2,540 410	56 37	5.9 6.6	4.0 4.0	102 16	
44	Columbus Ave. and New Heath St.,	None.	N	12(?)	C	30	128.49	16.0	(94)	133 (94)	128.5(?)	(?)	18 x 24 18 x 30	10 18	8	8	22	42	16	Clay,	61	550	69	15.1	4.0	22	
45	Columbus Ave. and New Heath St. (automatic controlling gates just below this point),	None.	N	36	P	28 x 60	(?)	15.8	(93)	133 (94)	(?)	E	30 x 36 60 x 78 36 x 48	50 (133) Intc. 57	102	102	20	572	16	Clay,	40	6,930	68	10.9	5.0	375	Overflow from intercepter.
46	Columbus Ave. and Centre St.,	None.	N	8	C	24	137.42	15.8	(92)	73 (94)	137.08	(?)	30 x 30	43	23	23	19	114	15	Clay,	68	1,190	54	10.4	4.0	47	Tributary sewer under head discharges much more.
47	Columbus Ave. and Ritchie St.,	None.	N	23	P	73 x 87	137.46	15.4	(65)	68	136.87	E E	24 x 36 28 x 48	15 40	233	233	21	870	9	Clay, In doubt, 30 per cent.,	60	7,960	29	10.6	4.0	320	Tributary sewer under head discharges much more.
48	Centre St., near Amory St.,	None.	N	18	C	18	152.92	–	(45)	58	154.78	C	18	6	25	25	36	150	15	Clay,	44	2,180	87	16.8	4.0	87	
49	Amory St., near Centre St.,	None.	N	50	C	36	138.85	–	–	–	135.60	E	54 x 70	92 Intc.	(See 53)	(See 53)	–	–	–	–	–	–	–	–	–	–	
50	Amory St., beyond Centre St.,	–	N	16	P	16 x 30	139.7±	–	–	–	135.9±	E(?)	30 x 36	21	(See 47)	(See 47)	–	–	–	–	–	–	–	–	–	–	
51	East of N. Y., N. H. & H. R.R. tracks, opposite Hoffman St.,	None.	N	34	P	39 x 56	137.14	10.3	(45)	(93)	135.11	E	24 x 81	54	51	51	25	397	21	Clay,	30	3,100	61	8.7	4.0	124	
52	400± feet North of Boylston Sta.,	None.	N	34	P	30 x 37	137.33	–	–	–	136.20	C	12	5.5	(See 54)	(See 54)	–	–	–	–	–	–	–	–	–	–	
53	Boylston St. at Boylston Sta. (easterly),	None.	N	18(?)	P	32 x 49	136.60	9.8	–	(93)	135.53	E	49 x 66	69	50	50	30	300	22	Clay, Sandy,	30	1,960	27	9.8	5.0	98	Low overflow crest. Intercepter overflow.
54	Boylston St. at Boylston Sta. (westerly),	None.	N	30(?)	P	30 x 48	129.33	–	–	–	133.78	E(?)	30 x 48	45	114	114	16	456	12	Clay, 70 per cent., In doubt, 20 per cent., Sandy, 10 per cent.,	30	3,700	33	8.1	5.0	185	Low overflow crest.
55	Green St., at Boylston Ave.,	None.	N	30	C	30 x 38	130.06	7.4	(19)	37	137.05	E(?) E(?) E(?)	46 x 56 30 x 41 30 x 36	21 18 55	200	200	18	960	10	Clay,	50	7,500	37	6.9	5.0	397	Intercepter overflow. Storm drain in this area takes about 25 per cent. storm water.
56	Green St. and Boylston Ave. (not in operation at present),	–	–	–	–	–	–	–	–	–	–	–	–	–	(See 55)	(See 55)	–	–	–	–	–	–	–	–	–	–	
57	Washington and Keyes Sts.,	1 B	N	28	C	36	131.49	4.3	–	21	133.19	E	36 x 48	21	23	96	18	245	8	Sandy, Clay,	7	2,680	30	11.7	4.0	113	Intercepter overflow. Storm drain takes about 25 per cent. storm water.
58	South and Keyes Sts., Jamaica Plain,	1 B	N	–	C	36	139.87	1.6	–	45	(?)	E	30 x 30	45	16	16	31	75	14	Clay,	8	550	33	7.1	4.0	22	Intercepter overflow.
59	Woodman and St. Joseph Sts., Jamaica Plain,	1 B	N	17	C	36	144.97	6.0	–	30	148.58	E	30 x 30	30	243	190±	15	245	6	Clay, 90 per cent., Sandy, 10 per cent.,	47	2,600	11	5.1	3.0	78	Intercepter overflow.
60	Hyde Park Ave. and Tower St., Forest Hills,	1 B	N	30	C	18	[illegible]	[illegible]	–	21	[illegible]	E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Sandy, 70 per cent., [illegible]	[illegible]	[illegible]	20	–	3.0	35	
61	Washington St., at railroad crossing, Forest Hills,	None.	N	28(?)	R	30 x 34	133.0±	2.2	–	7	131.2±	E	36 x 48	21	438	337	19	670	6	Clay, 90 per cent., Sandy, 10 per cent.,	18	5,710	13	–	3.0	171	Intercepter overflow. Two 20-inch pipes limit quantity in intercepter.
62	Washington St., at crossing S. B., Forest Hills,	None.	N	31	R	20 x 27	134.85	–	–	–	132.28	E	36 x 48	21	(See 61)	(See 61)	–	–	–	–	–	–	–	–	–	–	Intercepter overflow. Two 20-inch pipes limit quantity in intercepter; 12-inch pipe under about 5-foot head limits flow in main sewer.
63	Washington and Kittredge Sts., Roslindale,	None.	N	10	E	28 x 42	176.97	0.5	–	14	176.14	E	28 x 42	14	182	(182)	25	250	6	Clay,	11	1,690	13	6.5	5.0	85	
64	Anawan Ave., near Central Sts., West Roxbury (said to be inoperative),	None.	N	–	(?)	None.(?)	221.57	0.3	–	–	–	–	–	–	219	–	–	–	–	–	–	1,000	5				Two catch-basins connect with this district.
	Totals and averages,	–	–	–	–	–	–	–	–	–	–	–	–	–	2,190	1,737	21	5,584	9	Clay, 83 per cent., Sandy, 11 per cent., In doubt, 6 per cent.,	25	53,350	31	–	–	2,970	

† The district regulator at Cabot and Ruggles Sts. controls these overflows directly.

‡ No tributary sewer. Secondary overflow from No. 41.

Overflows in CAMBRIDGE.

No.	Location of Overflow.	Tide Gates.	Reg. Type.	Reg. Size.	Channel Type.	Channel Size.	Elev. of Crest.	Dry-weather Flow.	Cap. at Cut-off.	Full Cap.	Elev. of Invert.	Trib. Type.	Trib. Size.	Trib. Capacity.	House Sewage (Acres).	Storm Drainage (Acres).	Street (Per Cent.).	Equiv. No. of Houses.	Roof Area (Per Cent.).	Formation.	Declivity.	Population.	Per Acre.	Per House.	Per Cent. Rejected.	Equiv. Population.	Remarks.
65	Binney and Portland Sts. (district regulator just below this point),	2 B	R	24 x 48	C	90 x 90	101.4	18.0	40.0	60.0	101.4 95.0	C X	90 x 90 38 x 34	121 16	(698)	698	23	4,737	16	Sandy,	5.0	45,000	64	9.5	2.0	900	During very heavy showers Binney Street may overflow at various other points in district. Area, Cambridge Field and Broadway Park included.
66	Massachusetts Ave. and Albany St. (part of Binney St. drainage area),	(?)	C	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
67	Talbot and Waverly Sts.,	2 F	R	18 x (?)	E	24 x 30	–	4.5	18.5	33.0	105.13 105.23	E E	26 x 20 24 x 30	9.4 7.9	29	29	29	36	9	Sandy,	6.7	1,200	41	13.5	3.0	36	
68	Granite and Pearl Sts.,	1 F	R	10 x 30	R	24 x 30	105.25	4.4	16.5	32.0	104.08	X	32 x 36	18	67	67	22	488	16	Sandy,	5.0	2,840	43	5.8	3.0	85	
69	Pleasant St.,	1 F	R	9½ x 30	R	30 x 40	103.30	4.2	15.3	28.0	102.69	X	32 x 36	16	64	64	23	409	18	Sandy,	5.0	3,520	55	7.1	4.5	157	
70	Western Ave.,	2 B	R	9 x 30	R	40 x 44	104.00	3.4	16.0	27.0	103.00	E	42 x 48	42	120	120	18	229	18	Sandy, 75 per cent., Clay,	11.0	7,330	61	7.9	3.0	220	
70a	Sands St. (continuous overflow, not connected to metropolitan),	O	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	108	–	–	–	108	Continuous overflow.
71	Plympton St. and River View Ave.,	1 B	R	9 x 30	X	48 x 54	104.72	3.3	10.3	24.0	103.37	X	48 x 54	89	408	408	18	1,678	9	Sandy, Clay, 25 per cent.,	5.0	8,870	22	5.3	3.0	266	Part of college yard included.
72	Dunster St.,	1 F	C	12	S	19 x 24	103.47	1.4	6.5	14.0	102.14	S C	19 x 24 and 12	20 1.2	23	23	18	91	9	Sand,	7.0	880	38	9.7	4.5	39	Part of college yard included.
73	Murray St.,	2 F	C	16	R	30 x 36	–	1.3	7.3	14.0	105.92	E E C	24 x 31 21 x 26 15	7.5 23.0 3.5	56	56	26	322	15	Sand,	7.0	1,020	18	2.6	4.0	41	
74	Bath and Mt. Auburn Sts.,	1 F	R	9 x 29	E	40 x 52	108.91	1.2	7.2	12.7	108.20	E X	40 x 52 24 x 36	54 22	215	215	21	614	17	Sand, Clay, 15 per cent.,	12.0	4,000	19	6.5	3.0	120	Area, Common included.
75	Willard and Mt. Auburn Sts.,	1 F	C	12	R	22 x 24	–	.9	3.7	7.8	–	S	32 x 24	27.1	28	28	19	87	7	Sandy,	11.0	490	17	5.0	3.5	17	
76	Sparks and Mt. Auburn Sts.,	1 F	C	12	R	30 x 36	106.82	.9	4.4	7.8	106.07	E	32 x 41	26	70	70	15	248	7	Sandy,	24.0	1,060	15	4.4	4.0	40	
77	Lowell and Mt. Auburn Sts.,	2 F	R	9 x 29	C	52 x 52	107.68	.8	5.2	7.8	106.39	E E	37 x 48 23 x 36	42 33	236	236	14	398	4	Sandy,	7.0	1,950	8	5.0	1.0	20	Includes partially developed areas.
	Totals and averages (by weight),	–	–	–	–	–	–	–	–	–	–	–	–	–	2,025	2,025	23	10,226	12	Sandy, 92 per cent., Clay, 8 per cent.,	7.0	78,100	38	–	–	2,100	

Recapitulation of Overflow Table.

LOCAL NAME OF INTERCEPTING SEWER.	Number of Overflows.	Capacity of Intercepting Sewer.	Present Capacity.	House Sewage Area Tributary to Intercepter.	Storm Drainage Area Tributary to Intercepter.	Per Cent. Street Surface is of Storm Drainage Area.	Per Cent. Roof Area.	Probable Formation, Clay or Sandy.	Average General Declivity Storm Drainage Area in Feet per Thousand.	Approximate Population per Acre sewered.	Approximate Population contributing Sewage to Overflow.	Per Cent. Sewage rejected from this District.	Equivalent Total Population continuously contributing Sewage.
West side intercepting sewer,	8	134	71	639	742	25	26	Sandy, 83 per cent., Clay, 17 per cent.,	7	82	52,140	2.7	1,416
Charles River branch (south metropolitan, after use of high-level sewer),	25	93	73	8,564	2,867	15	6	Sandy, 43 per cent., Clay, 39 per cent., Doubtful, 18 per cent.,	23	12	105,000 60,000	2.9	1,768
Stony Brook valley intercepting sewer,	28	73	58	2,701	2,280	21	12	Clay, 81 per cent., Sandy, 14 per cent., Doubtful, 5 per cent.,	21	34	94,480	4.3	4,048
Cambridge branch, north metropolitan,	13	60	40	2,025	2,025	23	12	Sandy, 92 per cent., Clay, 8 per cent.,	7	39	78,100	2.0	2,010
Totals from intercepters, and averages by weight,	74	–	–	13,930	7,923	10	11	Sandy, 51 per cent., Clay, 41 per cent., Doubtful, 8 per cent.,	16	23	320,820 224,820	3.3	9,246

Having in all cases intentionally adopted values which throw the margin of doubt and allowance for extraordinary seasons on the side of increasing the estimate of pollution, I am of the opinion that the real discharge of sewage into the Charles does not exceed in amount that which would come from the constant discharge from 6,000 to 7,500 persons.

Population.

For Cambridge, from assessed polls, multiplying by constant ratio; all other districts, except as below, estimated from census returns of enumeration districts furnished by Massachusetts Bureau of Statistics of Labor.

For Newton, Waltham and Watertown, *connected* population inserted from information furnished by chief engineer, metropolitan sewerage works.

Note that in all other districts entire population considered as tributary to sewers.

Signs and Abbreviations used in Overflow Table.

Types of tide gates: —

B = Barn door gate.
F = Flap gate.
1B = Single set barn door gates.
2B = Tandem or double set of barn door gates.

Types of sewers and of overflow channels: —

C = Circular.
X = Extended circle.
E = Egg shaped.
S = Flat stone top.
Q = Barrel shaped.
K = Catenary.
G = Gothic.
L = Elliptical.
R = Rectangular.
H = Horseshoe shaped.

Types of regulator nozzles: —

U = Opening in bulkhead.
C = Circular.
R = Rectangular.
N = Overflows having no regulator, in common sense. In the last case, height of segment of invert of tributary sewer, up to point of overflow, has been inserted in column of "size of regulator nozzle."

N. B. — Data in parentheses, doubtful.

Present Visible Pollution of the Charles Basin.

Inspection of Floating Rubbish and Defilement. — It is rare that one-twentieth part of the water surface of the present Charles basin appears otherwise than clean, even in a dead calm.

On clear, windy days, the floating rubbish is blown into the coves or against the lee shore, leaving say 99 per cent. of the entire area as clean as could be desired; while some small areas, like the angle near the Union Boat Club, are in a condition to call to mind descriptions of the Sargasso Sea. At low water, particularly in the season of spring tides and with a fresh breeze, the water for 10 to 20 feet in width on the windward edge of mud flats and at the base of the Charlesbank wall is of inky blackness and foul in smell, with the sewage-polluted silt churned up by the waves.

On the few days when no wind is blowing, a general cruise about the surface of the present basin at any stage of tide will reveal many long, broad, crooked, dirty streaks, winrows of dirt on the surface of the water, commonly from 5 to 50 feet in width and often half a mile in length, their location and contour depending on the height and set of the tide. The most widely distributed constituent of this dirt in the winrows seen on days with little wind is the particles of soot coming from the burning of soft coal, and this is doubtless much worse in the present year, during and following the great strike in the anthracite mines, than it will average in future; but there are found, mixed in with the soot, fruit skins, melon rinds, waste paper, chips, broken boxes and the miscellaneous rubbish and flotsam of a harbor, to a widely varying extent at different times.

Apparently these dirty stripes are mainly shore-wash of the dirt that had been accumulated against some part of the margin of the basin or in an eddy during a gentle wind, and had been stranded and afterward set afloat by the rising tide, and carried hither and yon by its current.

Sometimes these streaks are found accompanied by long, narrow, oil sleeks. I have seen some of these that were particularly nasty. The worst of them appear to come from the Cambridge gas works or from the Broad canal. The rubber factories on Broad canal, the power stations of the Brookline Gas Company and the Cambridge Electric Company apparently each contribute a part of this oil. It should be easy to keep it from entering, by the same good police inspection that maintains neatness in the metropolitan parks. The drains entering the river from several soap factories will also need to be put under police surveillance.

There is a good gentle to fresh breeze down the basin nearly all summer long, and these streaks or winrows of dirt are much less noticeable when the wind is blowing than in calm weather; with a strong breeze the rubbish and general flotsam is driven into some convenient eddy, while the floating soot and dust are wet down by the waves and disappear.

Apparently part of this flotsam may come from up river, and a considerable part of it may fall in along the shores of the basin; but, from watching the flood tide from a boat near the Craigie bridge, I have noted that much of the rubbish and dirt is brought up from the main inner harbor by the incoming tide.

Under the prevailing westerly wind of summer I have seen this floating rubbish sometimes accumulated in the angle near the Union Boat Club and up stream therefrom to an extent that literally covered the surface of the water, all the way for 100 feet out from the embankment and for a length of from 500 to 1,000 feet, with a most unsightly mass of floating rubbish, chips, melon rinds, banana skins, waste paper, etc.; and I am told that dead cats and dogs occasionally add to the variety found here under present conditions.

It is my opinion that 99 per cent. of this floating rubbish is unsightly rather than unsanitary or malodorous; and that, with the changing tidal currents stopped and the rubbish from the harbor kept out, as by the proposed dam, *substantially the whole of this floating rubbish could be removed promptly and very cheaply from the eddies or curves into which the wind would drive it, by the same kind of care that keeps waste papers and rubbish removed from the pathways of the parks, or the care that keeps dead weeds and leaves removed from the coves of many water-supply reservoirs.*

Inspections of Sewage Filth floating in Charles River.

During all of our summer's surveying of the basin a sharp look-out was kept for visible pollution, and the occasions were very rare when anything particularly noteworthy from sewer overflows was seen,— hardly more than half a dozen times in all.

I myself found only three opportunities to inspect a storm overflow of sewage. On each of these occasions, in cruising about the Charles River in a power dory I found considerable quantities of floating fæces that had apparently come in through the sewer overflows, and over several limited areas these were present in enough quantity to destroy the relish of pleasure boating for the time being. On each of these three occasions the probable source for the worst areas appeared to be the old Stony Brook conduit and the Hereford Street sewer overflow, and on two occasions the Binney Street overflow was almost equally bad; and on the last two occasions much of the material that was seen coming out was decidedly worse in appearance than ordinary sewage, and gave evidence of concentration of the filth.

On Friday, June 13, 1902, after a brisk rainfall of 0.35 inch that ended about 7.30 A.M. and some smaller showers that ended about 11.30 A.M., I noticed about noon, at one hour after beginning of flood tide, that many long streaks of foul matter and many fæces were floating in the water at various points between the Union Boat Club and Essex Street.

On Saturday, Sept. 13, 1902, after a rainfall of 0.11 inch, so gentle as to probably affect only a portion of the sewer overflows, and which, so far as I could see, at 3.15 P.M. had not affected the Cambridge Binney Street overflow at all, I made a careful inspection of both shores of the basin. At about 3.30 P.M., with tide at early flood, I noted very considerable quantities of fæces westerly from the old Stony Brook outlet, scattered by the incoming tide, with much turbid water on top of the salt water, and I concluded that all of this came out from the old 7 foot conduit from old Stony Brook. Near the St. Mary's Street outlet the water was found very turbid, and with every appearance that there had been an overflow. I was everywhere interested to note the thinness in depth of the layer of turbid fresh water on top of the salt water, and the exaggerated appearance thus given to the quantity of overflow from the sewer outlets. Long lines of shore wash and floating débris were found in many places between Craigie bridge and Western Avenue bridge; the only other noteworthy quantity of objectionable matter was a few scattering fæces near the head of the basin.

On Wednesday, October 1, during a moderate rain on last quarter of ebb tide, I made a careful inspection of the margins of the basin from Craigie bridge to the Essex-Brookline Street bridge.

The Hereford Street outlet, at 3.45 P.M., was found overflowing strongly, and thence all along down to the Union Boat Club I found a strip of water near the south shore, varying from 150 to 250 feet in width, strongly discolored with street wash and *containing many isolated fæces, and sundry areas, say 20 feet by 100 feet, in which the*

fæces were hardly more than a foot apart. This discolored water forms a layer not exceeding 6 inches deep, as plainly seen at the edges. The limits of the water from sewer discharge were very sharply defined.

The Binney Street overflow channel was found discharging strongly at 4.26 P.M. *Its cross-section was about 8 feet wide by 1.5 feet deep, with 1 foot per second velocity, thus giving a discharge of 12 cubic feet per second. This carried fæces, say 1 per square foot of surface,* and occasional patches of grease. There was a strong smell of coal gas in this sewer, and a line of recent tar and oil stain on the side walls of the sewer at about grade 3, as though some factory had taken this occasion to flush out some waste impregnated with coal tar. This overflow from Binney Street formed a belt of dirty water about 50 to 100 feet wide down along close to the new granite wall of the front, and as far as Craigie bridge. I have subsequently at low tide observed bubbles arising from rotting sludge banks over the same course.

At outlet of Broad canal, at 4.45 P.M., very bad gas, tar and oil sleeks were noted. Several of these patches were each ¼ acre in extent, and covered with scum uncommonly thick.

The general appearance of the river surface, as seen on a zigzag course, indicated, say, three to five times as broad a streak of discoloration on the Boston side as on the Cambridge side.

The St. Mary's Street outlet, at about 5.30 P.M., was discharging a strong current, perhaps 10 cubic feet per second, of highly colored storm water, which spread out in a broad, thin sheet, as carried down by the tide. I cruised back and forth in this for half a mile, and found it very different in quality of pollution from the Hereford Street and Binney Street overflows. I saw no floating fæces in it or other offensive matter, and its discoloration appeared to come mainly from street wash and from well-dissolved sewage.

The Muddy River conduit was discharging very vigorously into the Charles, and its water was very turbid.

On October 1, about 1.30 P.M., I also examined the outflow from the new Stony Brook channel into the Fens basin. It was turbid with street wash, and averaged carrying say 1 piece of fæces to each 10 foot square of surface. The rain up to that time had been gentle, and the side walls and street surfaces had not yet become washed clean by the rain.

From what has been told me by park employees and policemen, I have no doubt that the outflow in heavy storms is sometimes much more foul than I saw it.

On August 11 a rapid and heavy downpour of rain occurred, 0.848 inch falling between 1 and 3 P.M., most of it in a heavy squall about 2 P.M. Mr. G. L. Hosmer, in charge of our survey party, working near the Essex Street bridge, reported that the Cambridge-Talbot Street sewer soon began to overflow, and had not entirely ceased at 5 P.M.; and that the large amount of floating fæcal matter carried into the Charles by the Talbot Street overflow was very offensive during his afternoon's work of sounding.

During the same afternoon, between 2 and 4 P.M., another assistant inspected the Boston shore, but found no overflows. An inspection at several man-holes showed much sewage inside held back by the tide gates (high tide occurred about 5 P.M.).*

* The drawtender at Harvard bridge has described to me a most extraordinary discharge of floating fæces and similar foul pollution that he observed passing under this bridge, after some heavy storm of last year, but he says he never saw it so bad before or since. He says it ran with the ebb tide for "an hour or two," and that the patches were "almost continuous, and averaged 40 feet wide." The assistant drawtender gave a similar description, and said they "could only account for it by supposing that some big sewer was being flushed out."

Favorable conditions for observation of outflow from the sewer overflows require that a brisk rainfall occur at about the time of low tide in the hours of daylight, and preferably within ordinary working hours; and there have happened but few storms during the past summer on which we could make complete observations.

Our summer's observation of the visible pollution can be briefly summed up by saying: —

In the Fens basin, it is certain that a disgraceful nuisance now exists and that its water is so foul as to drive pleasure boating from its surface.

The surface of the Charles basin is now in time of storm made very turbid by street wash from sewer overflows for several hundred feet in width along its margins, but this turbidity is superficial, mainly non-putrescible, and soon subsides.

In both the Fens basin and the Charles basin under present conditions somewhat infrequently after heavy rainfall the water surface for long strips 50 to 150 feet in width is defiled and made repulsive by large quantities of floating excrement and other filth, flushed out from the sewers by the storm water; and, if marginal conduits are provided in connection with the dam for collecting these sewer overflows, the appearance of the basin after storms will become greatly improved.

In the Charles basin during the past season I have several times seen conditions around the Union Boat Club float and in other eddies where the water was defiled and made most repulsive in appearance by fruit skins, waste papers and miscellaneous dirt and rubbish floating so thickly together that the surface of the water was almost completely covered for an acre in extent.

It is certain that there are conditions of foulness occasionally occurring on the larger basin of the Charles which should be prevented, as unworthy the location and the surroundings, whether or not the proposed dam is constructed.

It is certain that a considerable portion of the floating rubbish in the Charles basin is brought up from the upper harbor by the flood tide.

After frequent personal inspections throughout the basin I am of the opinion that, with the dam built and the basin at constant level, a moderate amount of park police work will maintain the basin with a much better appearance of cleanliness of water surface than it presents under present conditions.

Sewer Overflows are Small during the Warm Season.

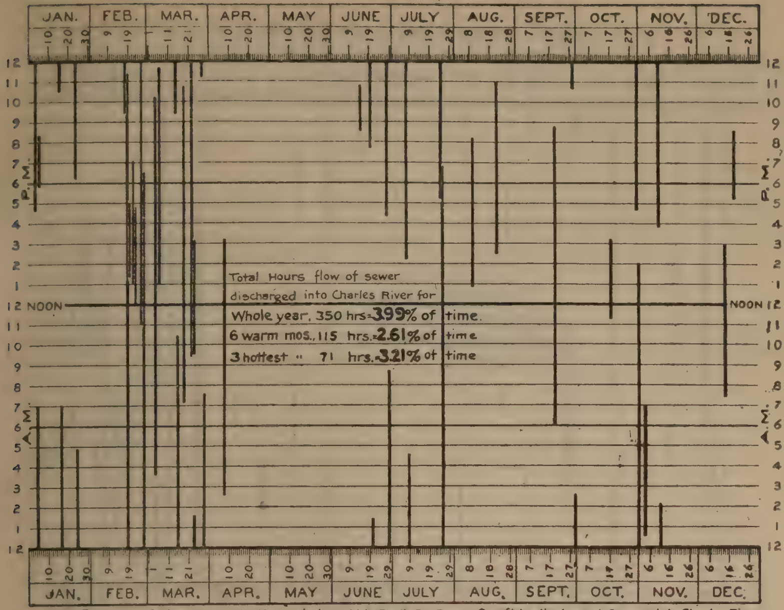
The following diagrams are similar to the diagram presented with Professor Porter's report on page 414 of the volume of evidence, but are made up from the revised and corrected records. They have an important bearing on the question of marginal conduits, because of exhibiting very plainly the fact that the overflows of sewage come chiefly in the stormy months of February and March and when snow is melting; and that during the summer season, when the dilution by upland water is least, and when alone putrefactive or offensive conditions could

occur, and when alone the use of the basin for pleasure boating would bring any slight pollution into notice, the overflows of sewage are few and their duration brief.

The vertical lines on these diagrams exhibit the time and duration of every sewer overflow for the year.

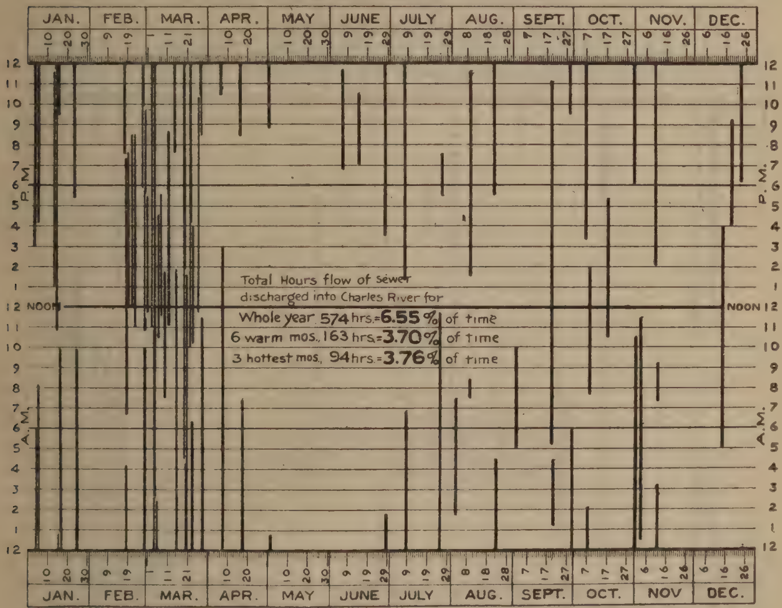
The length of the line shows how long the discharge continued, and the position of the bottom and top of line show the hour when the overflow began and ended.

BINNEY ST. OVERFLOW-1899



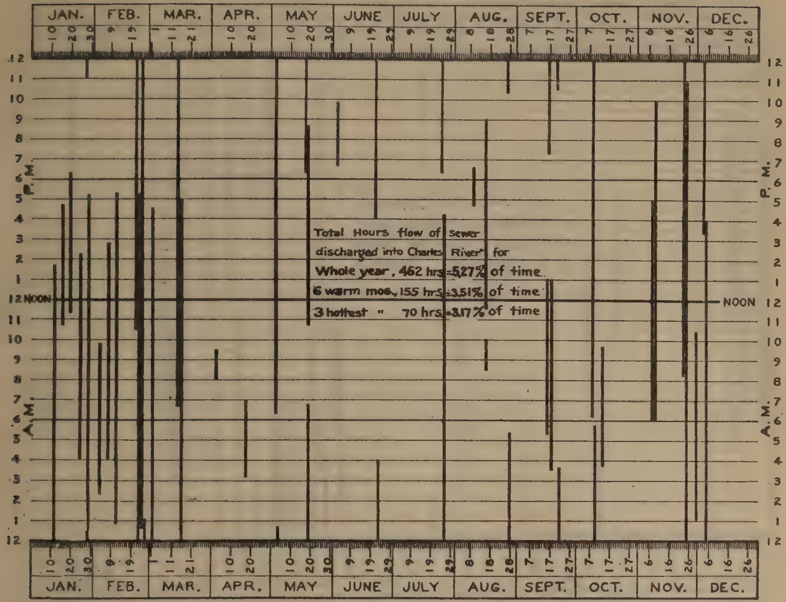
The Length of Line shows the Hours during which Bath St. Sewer Overflow discharged Sewage into Charles River

BATH ST. OVERFLOW-1899



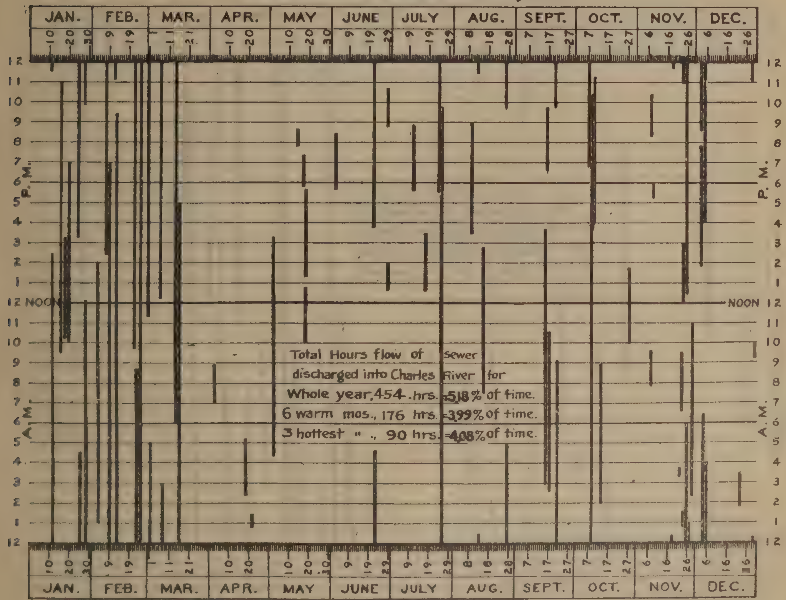
The Length of Line shows the Hours during which Bath St Sewer Overflow discharged Sewage into Charles River

BINNEY ST. OVERFLOW-1900



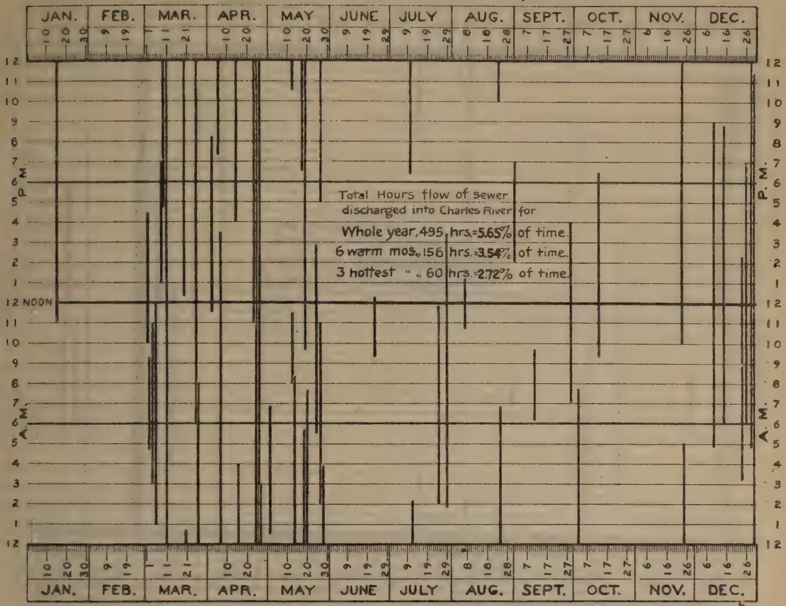
The Length of Line shows Hours during which Binney St. Sewer Overflow discharged Sewage into Charles River

BATH ST. OVERFLOW-1900



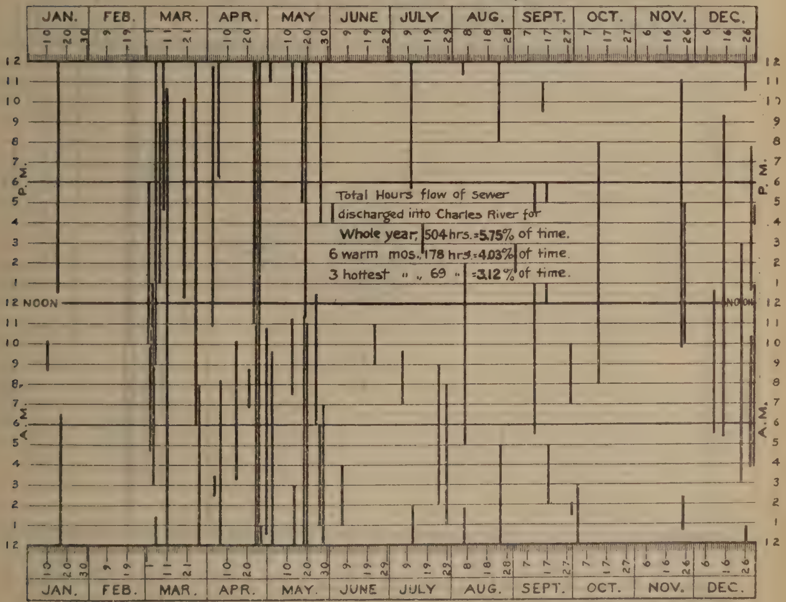
The Length of Line shows the Hours during which Bath St. Sewer Overflow discharged Sewage into Charles River.

BINNEY ST. OVERFLOW-1901



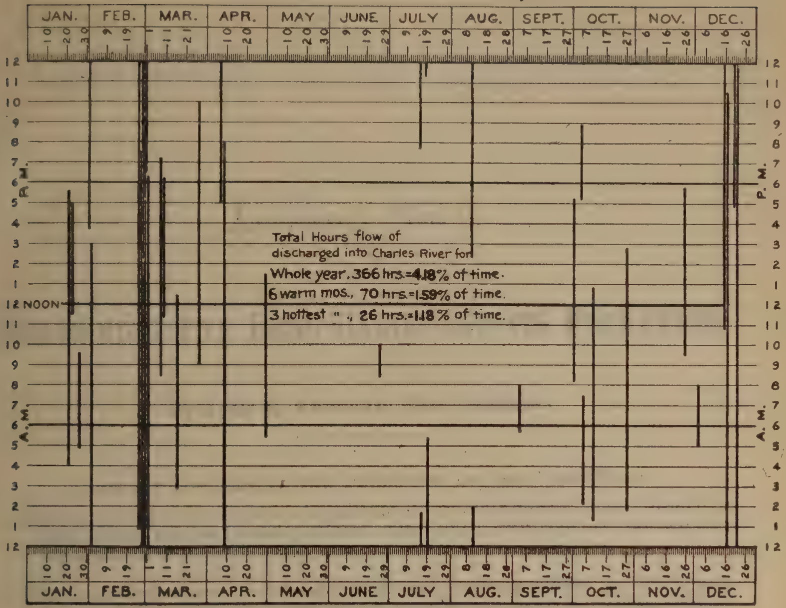
The Length of Line shows Hours during which Binney St. Sewer Overflow discharged Sewage into Charles River.

BATH ST. OVERFLOW-1901



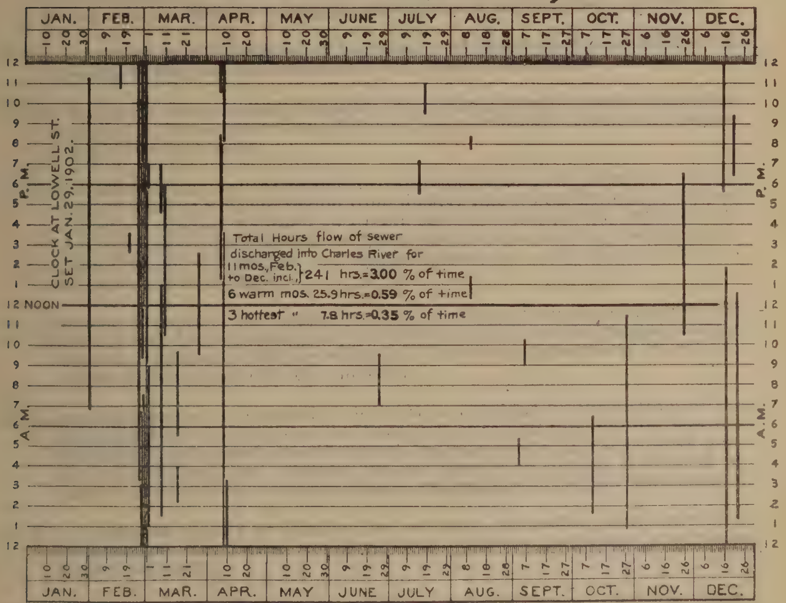
The Length of Line shows the Hours during which Bath St. Sewer Overflow discharged Sewage into Charles River.

BINNEY ST. OVERFLOW 1902



The Length of Line shows Hours during which Binney St. Sewer Overflow discharged Sewage into Charles River.

LOWELL ST. OVERFLOW 1902



The Length of Line shows the Hours during which Lowell St. Sewer Overflow discharged Sewage into Charles River.

Appendix No. 3.

Concerning the Fens Basin and its Pollution.

By John R. Freeman, *Chief Engineer*.

Abstract concerning the Pollution of the Fens Basin.

1. The Fens basin is on the site of a portion of an old tide mill pond, formed in 1821, which received much polluted street wash, drainage and sewage during a period of more than fifty years.

2. This basin had become intolerably foul and stinking before the Fens park was ever planned, and, indeed, the Fens park and basin were designed and constructed as a means of remedying intolerable unsanitary conditions, and did work a great improvement, and would probably have been inoffensive to-day had the plans of the engineers who constructed it been adhered to.

3. The construction and dredging of the Fens pond removed or covered the old deposits, so they are not responsible for present conditions.

4. The designers never intended that the Fens basin should receive the fouled fresh-water, dry-weather flow of Stony Brook or Muddy River, but planned it as a salt-water basin.

5. By the construction and extension of the "commissioners' channel" for the relief of the Stony Brook region from floods *without first building the short connecting conduit* required to divert the dry-weather flow into the old 7-foot by-pass conduit, the fouled fresh water was taken into the salt water of the Fens, in violation of the original plans, and with this the most of the present trouble began.

6. A temporary cause of the trouble was the breaking of the main sewer of the Stony Brook district during the construction work on the commissioners' channel extension in 1897, by which all the sewage from about 90,000 persons entered the basin for two months.

7. A cross-connection, understood to have been provided in the bottom of the commissioners' channel near its lower end, by which this foul dry-weather flow might be diverted into the main drainage sewers as a temporary remedy, has not been used, perhaps because these were already overtaxed by Charles River valley sewage and the storm drainage of certain low districts.

8. The attempted remedy by dilution has not been successful, partly by reason of defective circulation resulting from defective automatic appliances which leak badly.

9. Salt water acts to precipitate the pollution, brought down by the fresh water, as a foul, putrescent sludge or slime, as was clearly understood by the constructing engineer of the Fens twenty years ago. The lower one-fourth mile of the new conduit is filled 2 feet in depth with this foul sludge, and one-fourth part of the entire volume of the Fens pond is now filled with this nasty deposit, and this accumulation is still going on at a rapid rate.

The dates of certain events having an important bearing on conditions in the Fens are as follows: —

1821. Construction of tide mill dam, creating a salt-water mill pond covering site of present Fens basin, into which flowed two fresh-water streams that received constantly increasing amounts of pollution.

1851. Built Roxbury portion of the old Stony Brook covered conduit.

1861. Commission appointed to consider plans for laying out and sewering Back Bay streets; discharge to Fort Point channel proposed.

1863. Further official consideration of discharge of polluted water of Stony Brook; conclusion to discharge into Charles.

1865. Open channel below Tremont Street had become a foul nuisance.

1866–67. Old Stony Brook channel covered from Tremont Street crossing down to tide water.

1866. Final abandonment of use of basins by tide mills.

1867. Built present old Stony Brook gate house, now at south-east corner of Fens.

1870. Sluice gates of old tide mill pond torn out; tide now falls so as to uncover foul mud banks; mill pond region intolerably offensive.

1873. Built open walled channel for Stony Brook up from Roxbury line to Forest Hills.

1875. Foul mud banks exposed by low tide become so offensive that loose rock-fill dam was built in old sluiceways to hold water over them; result was little or no improvement; the stagnant or sluggish water received all sewage of tributary region, and became intolerably foul.

1876. Sluice gates proposed for flushing out pond, covering the foul mud flats; offensive conditions continued.

1877. Filling of portions of old mill pond "full basin" begun.

1880. Report by F. L. Olmsted.

1879–80. Construction of marginal roads or embankments of present Fenway.

1881. Built auxiliary Stony Brook channel from Roxbury crossing up to Linden Park, for increased flood capacity; Stony Brook intercepting sewer begun. Construction of present Fens Pond begun by deepening a portion of old mill pond, by dredging from 2 to 5 feet out of its bottom, and filling up other portions. This work carried on actively in 1881–82.

1882. In July completed 7-foot wooden conduit from old Stony Brook gate house.

1883. Completed Muddy River conduit to Charles River.

1883. Dredged out sludge formed near old Stony Brook gate house since its construction in 1867.

1884. Boston main drainage system put into operation, discharging sewage at Moon Island.

1889. Brighton intercepting sewer built, and Charles River valley metropolitan sewer.

1889. First two miles of new Stony Brook channel (commissioners' channel) completed.

1897. Foul dry-weather flow of Stony Brook returned to Fens basin through extension of commissioners' channel; break of sewer put sewage of 90,000 persons into Fens for two months.

1897. Present offensive conditions begun.

1898. Sludge deposits in Fens basin partially dredged.

That the waters of the Fens basin are foul and offensive has been fully brought out by the testimony and by the correspondence submitted to the committee, and can be quickly seen on a hot summer's day by any competent observer; and if the observer will repeat his visit and observe the outflow from the new Stony Brook conduit about half an hour or an hour after the beginning of a brisk rain he will conclude that overflows of sewage are the main cause, while the polluted dry-weather flow is also an important cause.

It has been suggested in the evidence (Porter, p. 413) that, if the proposed Charles River dam is built, the condition of the Charles basin is likely to become similar to the present condition of the Fens basin, and the same idea has been presented by others.

The fact that we have here in the Fens a basin of considerable size, originally a part of the tidal estuary of the Charles, whose outlet has been closed by a dam, so that the tidal range is greatly restricted, and which has become distinctly offensive by reason of pollution, notwithstanding that its water is kept in circulation and diluted by the admission, twice each day, of a large volume of salt water from the harbor, and that what was expected to become one of the most attractive features of the park system, with boating on its surface, has not fulfilled the expectations, surely warrants a very careful investigation.

Moreover, the proposed transformation of the main tidal estuary of the Charles River, having now a rise and fall of 10 feet, into a basin held at a nearly constant level, would require a radical change in the method of producing a circulation of the water in this Fens basin. Some pollution will unavoidably enter this Fens basin, and it becomes very important to understand the conditions that govern the amount of circulation required.

That the present amounts of dilution and circulation are proved failures as remedies for the present amount of pollution is generally accepted.

The faculty of Tufts College medical and dental schools, located near the Fens, a short distance east of the Stony Brook outlet, who, from their position and line of daily work, should be well able to judge of the condition of the Fens, presented a formal communication (evidence, p. 83), calling particular attention to the sewage discharged into the Fens basin, and to the dangers that they apprehended of unsanitary results without other provision for maintaining the purity of the water than appears in the Joint Report of 1894.

The present Fens basin has become offensive, mainly by reason of continuous pollution of its water in addition to the occasional storm overflows of sewage, and because of putrefying deposits of sewage sludge. But with these causes removed it may be thought that there remains a possibility that deposits of silt and organic matter laid down in the old mill pond, of which this basin is a remnant, may unfavorably affect the character of the water; therefore, a review of the history of the construction of this basin becomes important, and before expressing too harsh a judgment on present conditions it is well to understand what a great improvement has been made here over the conditions of twenty years ago.

History of Back Bay Fens.

The Fens are in territory which was originally occupied by salt marshes and mud flats of the tidal estuary of Stony Brook and Muddy River. The Fens basin occupies the deepest part of this ancient estuary.

This estuary, together with a much larger area of tidal flats lying

between old Boston and Gravelly Point, was enclosed in 1821 by the mill dam of the Boston & Roxbury Mill Corporation, on the site of what is now the extension of Beacon Street. The relation of the present Fens basin to the old tide mill ponds is shown by the map opposite this page.

The cross dam between the mill dam and Gravelly Point on the line of Hemenway Street, formerly Parker Street, divided the area enclosed by the mill dam into the "full basin," comprising the estuary of Stony Brook and Muddy River, and the "receiving basin," sometimes called the "empty basin," comprising the area east of Gravelly Point, which was at that time designated as the "Roxbury flats."

By the ingenious arrangement next to be described, it was made possible to run these mills continuously at all stages of the tide. None of the mills were located on the main dam, but all were on the cross dam. The full basin of 160 acres, with bottom 2 to 7 feet above city base, was filled at high tide, and was used as a storage reservoir by the tide mills to draw from during the succeeding low tide; while the receiving basin, being drained out at low tide, received the waste water from the mills during the following period of high tide.

This use of the full basin in connection with the tide mills continued for nearly half a century and ceased a few years prior to 1870; the tide mills above on Stony Brook at Wait's Mill (Roxbury Crossing) and the tide mill at Parker Street were abandoned earlier, the former about 1850, the latter at a still earlier date.

The filling up of the receiving basin to form building sites was begun at an early date, but the full basin, of which the Fens basin is a remnant, remained unchanged as to topography, although the old sluice gates were destroyed in 1870, and was not encroached upon, except by the crossing of the Boston & Albany Railroad embankment, until 1877, when the construction of the Fens park was begun.

The fact that the present Fens park and its basin occupy the site of the old full basin, which was by use a sedimentation basin for all of the sewers that there were in Roxbury and parts of Brookline and Brighton and for such other pollution as came down Stony Brook and Muddy River during the half century from 1821 to 1870, is of great interest, although after studying into these matters further this early deposit of sludge apparently has little or nothing to do with the present troubles.

The deposits that settled in this comparatively still, salt basin were generally covered by water prior to 1870, and the amount of water in circulation was large; but after the use of basin for tide mills ceased, and the old tide gates were removed, the deposits were disturbed by the more rapid and concentrated currents, due to the greater range of rise and fall, and exposed to the sun at low tide.

As the growth of the city encroached upon the margins of the full basin, the increasing amounts of sewage and manufacturing wastes from the water-sheds of Stony Brook and Muddy River, all of which flowed directly into this basin and added to the previous accumulation of filth, rendered its condition such that some relief became more pressing each year.

The construction of the Back Bay Fens and the conversion of the full basin into a park were the means adopted to improve the intolerable conditions that had come to exist in the old tidal estuary, caused by the exposure of the flats and by the sewage from the increasing population on the tributary streams.

Plans for Improvement of these Polluted Areas. — A general plan for the drainage of the whole territory tributary to the original Back Bay

RELATION OF THE FENS BASIN
TO THE FORMER TIDE MILL PONDS

was first formulated by a commission appointed in 1861 to consider plans for laying out and sewering Back Bay streets. In their report it was suggested that the future solution of the problem of Stony Brook, which they thought would probably fill the "full basin" with deposits in course of time, was to intercept the brook at Washington Street, and discharge everything through a large conduit and tunnel into Dorchester Bay. Further consideration, in 1863, decided against this proposition, as it was thought better to discharge Stony Brook into Charles River, where currents were swifter and change of water more frequent than with the sluggish tidal flow of Dorchester Bay. This, it must be remembered, was all prior to the conception of the grand plan of main drainage works for conveying the sewage of Boston to great storage reservoirs on an island in the outer harbor, whence the ebb tide should take it out to sea.

In Mr. F. L. Olmsted's report in 1880 he makes this statement of the conditions then existing in the full basin: —

"When the tide is in, it is a broad pool; when the tide is out, a narrow creek between broad, deep and fetid mud banks, in parts of which soundings have been made to a depth of 30 feet * without reaching firm bottom. Offensive exudations arise from the mud when exposed by a falling tide to a summer's sun, which are perceptible at a great distance." The old sluice gates, as previously noted, were destroyed in 1870, and after this the tide, although somewhat obstructed, ebbed and flowed from and to the basin.

The odors arising from the exposed flats became so offensive that in the summer of 1875 the water was held permanently at elevation 8 by a crude rock-fill dam, consisting of stone ballast dumped in the old sluices in the mill dam, in order that the flats should not be uncovered at low tide. This expedient did not relieve the situation, for the water in the hot summer months became so foul that it is said to have been quite as disagreeable as the exposed mud of the flats.

The next year a proposition was made to remedy the offensive conditions by replacing the dam by gates, through which foul water could be drawn and fresh sea water admitted; but it can not be learned that this was carried out. Some attempt was made each year until 1880 to change the water by removing some of the stone filling from the old sluiceways temporarily, and thus permitting the tide to rinse out the basin, and *it was not until the construction of the present Fens basin was well advanced, and the 7-foot wooden conduit was completed, in July, 1882, to take dry-weather flow of Stony Brook to the Charles River, that the condition of this basin became in a measure wholesome.*

A very interesting account of the construction of the Fens parkway, by Mr. E. W. Howe, of the Boston city engineering staff, is given in the first volume of the proceedings of the Boston Society of Civil Engineers, p. 126. Under date of March 16, 1881, Mr. Howe describes its early stages as

> "The purchase of 106 acres of the filthiest marsh and mud flats to be found anywhere in the State of Massachusetts, without a single attractive feature or anything to make it of except space; a body of water so foul that even clams and eels cannot live in it, and

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* This depth of 30 feet is incredible at this locality for mud of an offensive character over any wide area, but mud colored with carbonaceous matter may have filled some ancient gully to this depth.

The borings on the line of the commissioners' channel across the old natural channel of Stony Brook indicated a depth of mud or silt to elevation —13, Boston base, for a narrow space only, in the width of the old channel; but the distinction between ordinary alluvial mud or silt, that may be hundreds of years old, and the sludge arising from pollution, is not made clear in the two reports just cited.

that no one will go within half a mile of in summer unless from necessity, so great is the stench arising therefrom. . . . This is called the 'Back Bay Park.' It is more than twice as large as our grand old Boston Common, and the average citizen naturally concludes that its attractiveness will be in the same proportion. This expectation, I fear, is destined to be disappointed. But, for all this, I think the proposed improvement of this territory a wise step, *the mistake being in not making the sanitary necessity of the improvement the main question and the park feature of the plan subordinate to it.*" *

Twenty years later we find this park lake neglected, the design of the constructing engineers disregarded by admitting constantly the foul fresh-water flow of Stony Brook, and the fears of the constructing engineer realized for the time being, but fortunately not beyond remedy.

Mr. Howe said further: —

"The greatest difficulty to be met was the discharge of Stony Brook. The expense of extending the channel of this brook to Charles River, of such size as to carry the full flow at all times, would be very great, so great that it was thought best not to undertake it. . . . *But, as is well known, the discharge of polluted fresh water into salt water causes the deposition of a filthy slime which could not be tolerated in a place of this character. So it was decided to make the water basin in the park a salt-water basin and not admit fresh water to it at all except freshet overflow, as described later.* *

Among the many plans formulated for the improvement of the Fens, the recommendations of Mr. Frederic Law Olmsted, the eminent landscape architect, were finally adopted. It was planned to have a salt-water basin, held by a dam at elevation 8, *into which no fresh water was to be admitted*, excepting such occasional storm overflows of the old Stony Brook conduit as were in excess of the carrying capacity of the 7-foot extension to the Charles, and to reproduce in the land surface, as far as possible, the conditions that are found naturally on a salt marsh.

It was appreciated by those who planned this park that the Fens could not be maintained as a tolerably pure salt-water basin, if it continued to receive the so-called "foul flow," or dry-weather flow, of fresh water from Stony Brook and Muddy River; and therefore it was planned to divert from the Fens basin the *dry-weather* flow of Stony Brook, and the *entire* flow, including the storm water, from the much smaller watershed of Muddy River, and take these directly to the Charles; and *it is mainly since the return of the polluted dry-weather flow of Stony Brook into this basin in 1897 that its condition has become intolerable.*

It was considered necessary by the designers, in order to promote the active circulation of the sea water admitted from the Muddy River conduit and the 7-foot conduit, that the Fens basin should be narrow, and, in order to secure a desirable landscape effect and at the same time present a large area for storage of storm water, that the water surface should be winding and long, as is shown on the folding map inserted at p. 216. The water was consequently narrowed from the original area of about 190 acres between the cross dam and the mill dam down to an area of about 26 acres; and further provision was made for the storage of flood overflows of Stony Brook during high tide, by cutting down the land areas of about 20 acres that were to be included within the high marginal roads, from their original marsh level of grade 10.5,

* These italics are ours.

city datum, to an elevation but little above that of the proposed water surface, or to grade 8.5 to 9.0.

It was anticipated that these artificial marsh lands would be covered, in extreme floods, by from 1 foot to 3 feet of water, thus making a temporary lake of nearly 50 acres, composed largely of fresh water on top of salt water at such times; and it is interesting to note that, in the flood of February, 1896, the water in the Fens basin rose to elevation 11.8, or about 3.8 feet above the normal level.

It was also anticipated that this 20 acres of marsh might sometimes be flushed with salt water if desired.

It was because of the great expense that provision was not made for diverting the whole flow of Stony Brook in time of freshets through the by-pass to the Charles River, and thus keeping it out of the Fens. The distance to be covered was 3,600 feet, and so a conduit was constructed of wood, 7 feet in diameter, at an expense of $20 per linear foot, instead of attempting any such flood channel as the new Stony Brook conduit, 15½ feet by 17 feet, which cost about $100 per linear foot. It was not anticipated that the storm overflows alone of Stony Brook (comprising only the surplus flow beyond what this 7-foot conduit would carry), with its large dilution of the sewage contained, would give any trouble in the basin.

The Construction of the Fenway and Excavation of Present Fens Basin. — The filling of the marshes in this portion of the Back Bay was begun about 1877, but active operations on the Fenway park itself did not begin until 1879 and 1880, when its marginal roads were constructed of gravel brought in by rail from Weston and Wellesley.

In 1881 the excavation of that portion of the present Fens pond near its down-stream end, lying between Beacon Street and the Boston & Albany Railroad, was begun. This was completed by dredging in the following year. The old outlet of the basin, just east of the present outlet, was closed and partially filled, and the present dam and tide gates at Beacon Street were put in operation also in 1882.

Further dredging was done in 1882 from the Boston & Albany Railroad, up stream or southerly, to what is now Agassiz Road, digging it down to a level bottom at elevation 0, Boston base; and the material, which here was mostly gravel, was used in making the shore lines of the present Fens basin. With this gravel, and later with gravel hauled in by rail, the shore lines of the present basin were roughly shaped on a slope of 3 to 1, and carried to about grade 8, while the mud dredged from certain areas below Agassiz Road and the mud from over the whole bottom of that part of the basin lying up stream from Agassiz Road was used to fill the land areas lying behind these gravel slopes to elevation 8.5, or 9, Boston base.

The average depth of mud dredged from the bottom of the basin was 3 feet, varying from 0 at the lower end to 5 feet at the upper end, near the old mouth of Stony Brook.

Not all of the improved marsh land was formed from this dredged mud, but much of the filling was obtained from the cutting of the old marsh levels from grade 10.5 to the final grade of 8.5 to 9, for the purpose of flood storage, already mentioned.

This work was carried on during the following years, until, in 1891, the Fens basin was completed up to Brookline Avenue.

This basin was designed to be 8 feet deep in accordance with the opinion current among engineers that a depth of water of about 8 feet is necessary to prevent aquatic plants taking root.

During the construction of the Fens basin, the deposits of mud on the

flats within the limits of the present waterway were removed to grade 0. It was not thought necessary to remove any of this material below grade 0, as the 8 feet of water provided on top of this mud that remained was considered sufficient to effectually prevent any further trouble.

The dredging operations of 1883 removed the deposits of sludge, street wash, etc., which had been forming during the sixteen years since 1867, near the present structure in the Fens, known as the old Stony Brook gate house; but it was found, in the interval of five years between 1883 and 1888, when the basin was drawn to elevation 2.5, Boston base, that deposits were uncovered at the gate house on areas that had previously been dredged to elevation 0.

These deposits must have been caused by storm overflows of the old Stony Brook conduit. They were removed at this time, 1888. It is reported at the city engineer's office that this material then dredged, which was not large in amount, was composed of sewage sludge and of sand and gravel, some of which came from the construction work on the Stony Brook channels above.

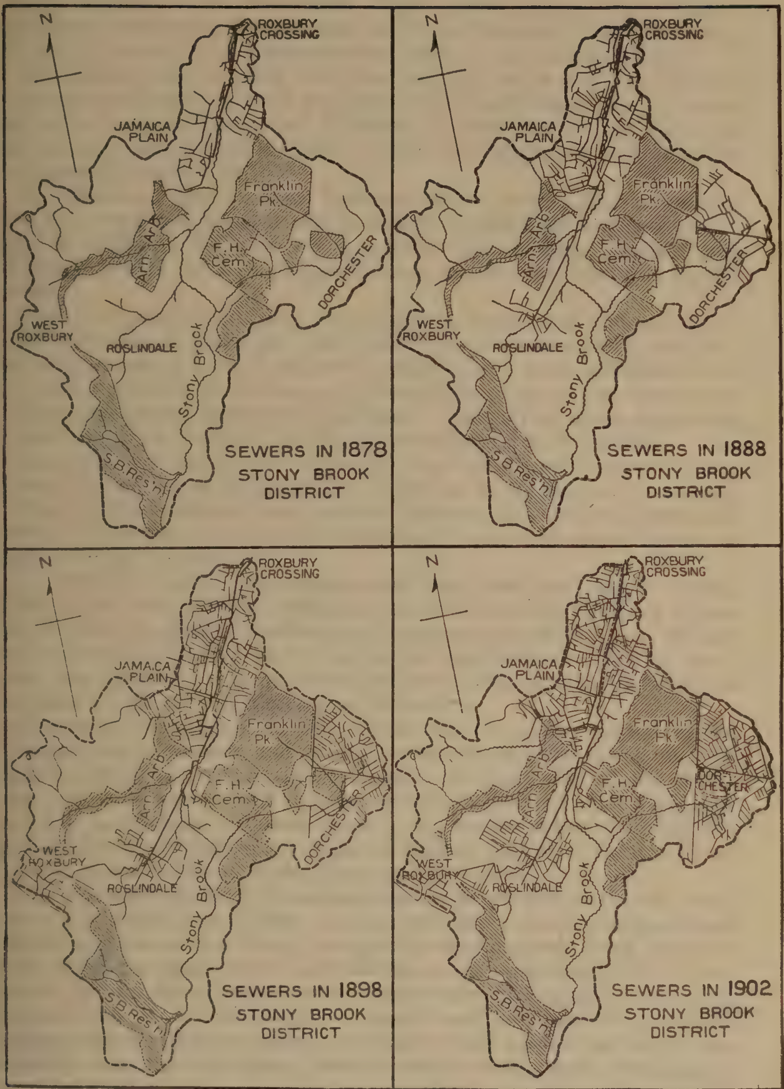
Although the Stony Brook intercepting sewer was completed in 1881, the main drainage pumping station was not in operation until February, 1884, so that Stony Brook conduit carried all the sewage of Stony Brook valley until this time, and while the 7-foot conduit delivered this to the Charles in dry weather, the overflows of mingled storm water and sewage were continually entering this basin; and, as the Brighton intercepting sewer was not built until 1889, the sewers that now overflow on Huntington Avenue at Parker and Bryant streets must still have been flowing into the old conduit until this date; consequently, the early storm overflows at the old Stony Brook gate house must have been much more offensive than the overflows subsequent to 1889, after this sewage was intercepted.

Stony Brook.

Stony Brook, which is found bringing most of the pollution into the Fens, drains an area of about 13.92 square miles in Hyde Park, West Roxbury and Roxbury, which now contains a population estimated at about 91,000. The upper water-shed has a comparatively small population, is scantily sewered, and is of open hill and meadow country with a clay subsoil; the lower part of the water-shed is thickly built with factories, stores and dwellings. The brook is about 7¾ miles long.

Throughout its course the brook originally flowed in an irregular channel, through low meadows and swamps, with but little fall. In its natural state Stony Brook ceased to be a fresh-water stream near the Boston Belting Company's present works at Elmwood Street, where it flowed into a small tidal bay, which contracted at the Boston & Providence Railroad to a narrow, well-defined channel, through which the brook flowed in a tortuous course to the broad estuary, which, after the construction of the mill dam, was known as "the full basin."

The natural channel was never sufficiently large to quickly carry away the run-off from heavy rainfalls. In the natural state of the water-shed the rough condition of the land, covered with trees and bushes, retarded the flow of surface water, and the low meadow land provided the necessary storage for a gradual discharge in time of flood. The commission of 1886 found an area of 690 acres of meadow land thus liable to be flooded at that date; but, as the valley became more and more fully occupied, the surface delivered the rainfall more rapidly,



GROWTH OF SEWER SYSTEM
IN STONY BROOK DISTRICT.

AREAS SHADED WILL BE PERMANENTLY LEFT OPEN AND WILL NOT REQUIRE SEWERS

and these natural reservoirs were in part filled up. Thus two causes were at work to increase the severity of floods along the lower channel. As the territory about the mouth of the brook became more thickly populated, the brook became foul, and was concealed from sight and smell by covering it in a rude conduit having scant channel way.

The first of this covering was done in 1851, when the city of Roxbury relocated and covered the channel of Stony Brook, from Vernon Street to Tremont Street and Whittier (Culvert) Street, but the work of covering for the entire distance was not completed until 16 years had passed, or until 1867.

In 1865 the channel below Tremont Street became such a nuisance that the brook was diverted and its course straightened by the construction, in 1866 and 1867, of a new covered channel from Tremont and Whittier streets through Rogers Avenue to the full basin at Parker Street.

This was mainly built with two channels, each 9 feet wide by 8 feet high, with double arch and centre wall, all of rubble stone laid dry, In some places of scant head room granite slabs were substituted for the arch. In some places no special foundation or bottom was provided.

The remarkably crude and inadequate character of these structures is well shown in Plate IV. of the commissioners' report of 1886.

During these two years (1866–67) the old channel above Vernon Street was walled in and partially covered, as far as Roxbury Crossing.

The right to construct the covered channels was obtained partly by formal taking and laying out for sewerage purposes, partly by agreement with the abutters.

In 1873 a channel was constructed from Roxbury line to Forest Hills; but it was not until 1884 that the channel from Roxbury Crossing to West Roxbury, consisting of a large open ditch 16 to 20 feet wide, with side walls 5 to 10 feet high, was finished. In this year, 1881, the auxiliary channel from Roxbury Crossing through Tremont Street and Linden Park Street was also built.

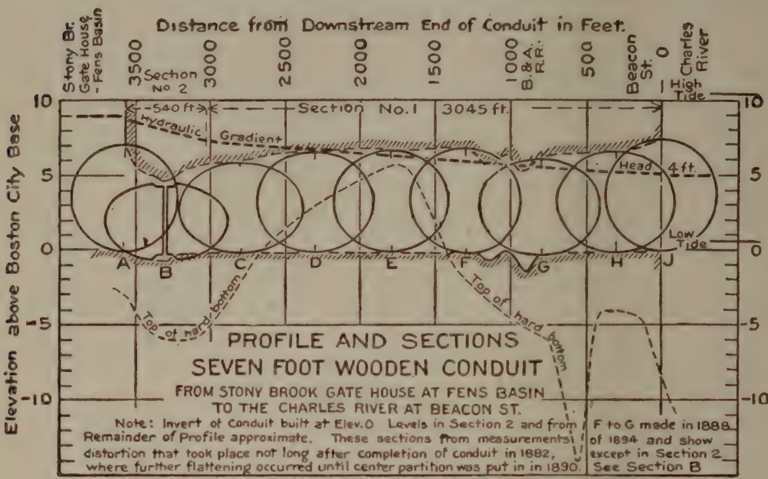
The rapid development of this region and the great change in the delivery of storm water and sewage overflow into the brook may be inferred from the accompanying maps. An inspection of the latest map and of the spaces now remaining without sewers and of the spaces that will permanently remain open is of interest when studying the probability of any further overload of sewage and storm water in its relation to the pollution of the Fens and the Charles.

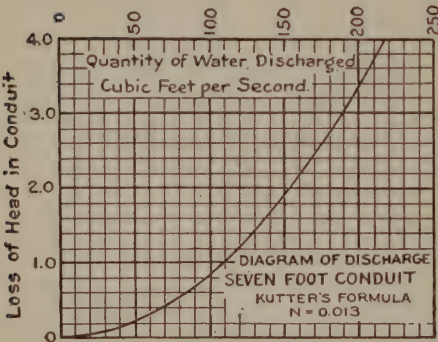
Stony Brook continued to discharge at Parker Street into the full basin of the old tide mills until 1880. Next, a temporary channel on the line of Rogers Avenue carried it out through the new marginal road, until, in July, 1882, the gate house now known as the "old Stony Brook gate house" and the new channel from Parker Street to the gate house were finished, and the dry weather flow was turned into the 7-foot conduit leading into the Charles River. This new 7-foot conduit had much less capacity than the old Stony Brook conduit above, and consequently overflow channels were provided at the gate house, through which, in times of heavy rain, the surplus of storm water, mingled with sewage overflows and street wash coming down the old conduit, was discharged directly into the Fens basin.

The Seven-foot Wooden By-pass Conduit.

This has been reviewed in some detail, mainly with a view to the possibility of utilizing it, in a manner to be later described, for removing the polluted water from the Fens basin, and thereby deferring for some years the expense of a new and larger conduit.

This extension of the old Stony Brook conduit to the Charles, completed in 1882, was of circular section, 7 feet and 2 inches in diameter





Hydraulic Elements of Seven Foot Wooden Conduit.

Section of Conduit See Profile	Area of Full Section Sq. Ft.	Length of Wetted Perimeter Feet	Hydraulic Mean Radius
A	38.5	22.1	1.75
B	32.8	30.9	1.06
C	39.2	22.4	1.75
D	40.8	22.6	1.81
E	40.3	22.2	1.82
F	40.0	22.2	1.80
G	40.5	22.5	1.80
H	42.1	22.5	1.87
J	43.0	23.1	1.86
Mean of Sect. 2	35.8	33.4	1.07
Mean of Sect. 1.	40.8	22.6	1.81

Note. — Above computation supposes conduit full or nearly so, and that water at gate house is at elevation 9. Reference to preceding diagram will indicate effect of lower head at entrance or lower tide at outlet.

and about 3,600 feet in length; its invert was at grade 0 and approximately level from the gate house to the river, and it is said to have been designed to give a maximum discharge of 160 cubic feet per second. The extra 2 inches in diameter was added to afford room for a future plastering with cement, if found desirable; 167 feet at lower end was so plastered.

Its walls are of wood, 8 inches in thickness, and were made of 2-inch spruce plank, 8 inches wide, the width of the plank set radially and the plank placed longitudinally and pinned together with oak tree-nails,

Dry Rubble Arched Culvert, Old Stony Brook.

(At this place roof arch had sagged and some of the stones had fallen out. Heavy timber frames were set at this particular spot, but much more of this kind of construction remains, liable to cave in at any time.)

every fourth plank having sufficient taper in its width to give the proper curvature to the conduit section.

The construction did not prove sufficiently stiff to prevent distortion, due to the superincumbent weight of earth; and the conduit changed in section throughout its entire length shortly after its completion, from a circle 7 feet in diameter to a section approximately an ellipse, 6 to 7 feet in height and from 7 to 8 feet in width, as shown on the profile on opposite page. Except for a section of the pipe near the gate house, the conduit showed no increased distortion after the first few months, but for a distance of 536 feet below the gate house this distortion became much greater; and in 1890 it was thought necessary to put in a partition in the centre, to prevent the collapse of the structure, for the conduit had flattened at the point of maximum distortion from 7 feet to 5.24 feet, and correspondingly increased in width from 7 feet to 8.45 feet.

The conduit grade, originally at elevation 0, Boston base, showed slight and irregular settlement in a few levels taken in 1888. The greatest settlement found was about 9 inches, except for a section near the Boston & Albany Railroad, where tradition or rumor says a maximum depression of 1.5 feet was caused by a mistake in construction. It is reported that this conduit was regularly inspected by the city engineer's department until a very few years ago. The material of the conduit walls is reported to be in good condition at present, preserved from decay, no doubt, by its constant wetness from the tides which daily rise above its top.

Since the top of the outside of the timber is at grade 7.7, the conditions for its preservation will continue favorable with the level of the Charles basin at grade 8.

The present carrying capacity of this conduit, under different losses of head, from the gate house to the Charles River, is computed to be as exhibited in the diagram given on opposite page.

This conduit has its present outlet into the small pond between Beacon Street and the river wall. When the conduit was built, it was intended that it should be eventually extended to the Charles River across the 150 feet intervening, and make this small pond a part of the Fens basin, but this has not been done up to the present time. Another plan was to arch this space over, and make it a sunken garden.

Present Condition of Old Stony Brook Conduit.

The reported putrid deposits in this conduit are probably a menace to health, or might perhaps become so in time of epidemic.*

Some old house sewers are reported to still discharge into it all of the time, there being no other convenient sewer into which they can drain.

As stated in evidence (Emerson, p. 7), this channel in Rogers Avenue and other streets between the Fens pond and the Boston Belting Company, for nearly its entire length of 4,600 feet, is in very bad condition, and will have to be rebuilt in the near future.

This is particularly true of that portion about 1,000 feet in length that was built in 1851, the covering of which is long stone headers, that have a span of from 9 to 10 feet. It is reported that these stone slabs

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* I am informed by Mr. A. L. Kidd, C.E., of the sewer division, that the rough condition of the rubble stone work and the many braces placed within it to keep its roof from falling down have caused the channels to collect large quantities of sludge. In many places a crowbar can be pushed down two or three feet below the normal bed. The ordinary flow follows the north channel, and in the south channel about a foot in depth of soft sludge and mud has gathered for nearly its entire length.

have broken in places, and at a point on Whittier Street east of Tremont Street the southerly channel has become almost entirely obstructed.

Mr. A. L. Kidd, C.E., of the sewer division, tells me that in September, 1896, he counted 21 of these roof stones cracked, and it is said that this breakage is continually increasing. Many of the timber props are reported badly decayed.

The section built in 1866 and 1867, from Tremont Street to Parker Street, about 2,200 feet in length, was covered with rough stone arches, now supported in place by timber props and shoring, and in which it is reported many of the stones are loose and some have fallen. Where the channel passes under Huntington Avenue, to make safe the passing of the heavy electric cars and teams the channels had brick arches built in for the full width of this street.

The small piece of covered channel above Vernon Street is for most part covered by Tower's factory, and elsewhere is covered with plank.

The short down-stream section of the old conduit from Parker Street to the gate house, 325 feet in length, was evidently well built; and our inspection shows that it is still in good condition, but has a deposit of about 1 foot in depth of sludge on its bottom, through which one sinks at every step. Up to the present time we have not found opportunity to go through this conduit above Parker Street, as intended, for purpose of inspection and in order to search for points where pollution constantly enters.

It is said that the old conduit, as a whole, is at present very foul, as it has not been thoroughly cleaned out for sixteen years, since 1886, just after the flood of that year. It is reported that many deep pools exist in the length of conduit, where incoming storm overflows have in the past scoured the unprotected earth bottom, and that these are now filled to a greater or less depth by sewage sludge, and that from these pockets of sludge bubbles of the gaseous products of putrefaction arise in warm weather. In addition to the gases of putrefaction, marsh gas, etc., it is also reported that there is probably some escape of illuminating gas into it; and, altogether it is said to be unsafe to go through it except with the most thorough precautions as to ventilation, and due regard to storm water and the stage of the tide.

The open channel at the present head of the conduit, below the Boston Belting Company's works, is a nuisance at those times in the summer when the Belting Company is not discharging its two million gallons or more, per twenty-four hours, of clean, warm condensation water, and the bed of the brook is exposed to the hot sun, as it commonly is on Saturday afternoons and Sundays.*

The head of the old channel is now within the yard of the Boston Belting Company, and for a few hundred feet above this point the old Stony Brook conduit has been completely filled up and obliterated, and below that point it now carries only the condensation water from the Belting Company's works, together with the old storm overflows of the sewers, the street wash and surface drainage of its immediate territory, and perhaps some manufacturing waste and an undetermined amount of house drainage, also some ground water.

In dry weather, in working hours, from rough weir measurement, we estimated the total flow of the old conduit at the gate house in the Fens to be about 10 cubic feet per second, including the condensation water

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* This open channel appears to form a convenient receptacle for the rubbish and dead cats of the neighborhood, and is frequently cleaned out by the sewer maintenance gang. They probably do not go very far down into the covered conduit for this, for most of the rubbish is of a kind that is not carried far by the current. They intend to inspect this and clean it each Friday or Saturday, and commonly obtain about twelve wagon loads each week, or about 240 cubic feet of tin cans, ashes and rubbish in great variety.

Old Stony Brook Channel. Showing Defective Arch supported by Timbers.

Old Stony Brook Channel. Showing Broken Slabs of Granite forming its Roof.

from the Boston Belting Company. This flow varies from night to day with the working hours of the Belting Company, whose stated draft of 12,000,000 to 15,000,000 gallons per week of metropolitan water, or, say, 2,000,000 gallons per day, concentrated into the 10.5 working hours, would average 7.1 cubic feet per second for this time. Without the condensation water, by one measurement on Saturday afternoon and by another at 8 P.M., the flow at the gate house, which is made up of ground water, manufacturing wastes and house drainage, was found by weir measurement to be about 3 cubic feet per second.

The New Stony Brook Conduit.

It is through this conduit that nearly all of the present pollution comes into the Fens basin.

In February of 1886 a great flood in the Stony Brook valley caused such an amount of damage, because of insufficient capacity of the old Stony Brook conduit, that, under the recommendation of a commission of eminent engineers appointed to advise in the matter, a new and very much larger channel, still often called the "commissioners' channel," was constructed in 1888 and 1889 at a much lower level than the old channel, from the Fens basin at Huntington Avenue up through Parker Street and alongside the Providence Railroad to a temporary head basin, with screens and gates and overflow connections located near Roxbury Crossing.

This overflow chamber was built at the site occupied by the present gate chamber above Tremont Street, near Roxbury Crossing, at which point the dry-weather flow or "foul flow" of Stony Brook was discharged into the old Stony Brook conduit, and thus kept out of the Fens, while only the excess of storm water was permitted to overflow into the new commissioners' channel. This conduit was first put into regular use for the discharge of the flood water into the Fens basin in December, 1889, although a flood of January, 1889, was discharged through the uncompleted channel.

In the year 1897 the old conduit was completely cut off at Roxbury Crossing by the extension of the commissioners' channel up Columbus Avenue at a much lower grade than the old conduit, and the old "auxiliary channel" was divided and used, one part for a sewer and the other for a surface drain.

Therefore, since 1897 the "commissioners' channel" has carried directly into the Fens basin the whole "foul flow" and "storm flow" from all that portion of Stony Brook valley above Roxbury Crossing.

It was during the summer of 1897, after the dry-weather flow had begun to discharge into the Fens basin, that the Stony Brook valley sewer in Columbus Avenue was broken during this extension of the new Stony Brook conduit; and for about two months (see evidence, p. 128) the whole flow of the Stony Brook valley sewer discharged into the Fens basin. A similar accident occurred in 1900, and all of the sewage of the 90,000 population of the Stony Brook valley was again discharged into the Fens for parts of three days.*

The large conduit, or "commissioners' channel," has been extended up the valley, year by year, until in this summer of 1902 it has reached a point just above Green Street, Jamaica Plain, nearly three miles up stream from its point of discharge into the Fens basin; and it is proposed to carry it further from year to year.

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* Breaks occurred Aug. 14 and 16, 1900; sewage flowed into Fens basin intermittently during these two days. On or about Oct. 10, 1900, while broken sewer was under repair, sewage flowed into the new conduit and thence into the Fens for about ten hours.

Muddy River.

Muddy River drains an area of 5 square miles, principally in Brookline and Roxbury, including Jamaica and Leverett ponds.

This area is less thickly populated * than Stony Brook, and is wholly a suburban residential district. Moreover, this stream differs still more from Stony Brook, in that the river and the two ponds which it drains are included in the Boston park system, and, by the margins being thus guarded, there is little or no possibility for raw sewage to enter it in dry weather. Considerable pollution enters in the form of street wash, and one sewer overflow is said to sometimes discharge into it.

Until the completion of Muddy River conduit, in 1883, Muddy River had always flowed into the Fens basin, formerly known as the "full basin" of the Boston & Roxbury Mill Corporation. The flow of Muddy River at the time of the Fens improvement was of course not so large, but was quite as objectionable, as that of Stony Brook; for this little river then received the flow of sewers in that portion of Brookline that bordered the river. At present, as stated above, there is but one sewer overflow tributary to Muddy River, and this, the town engineer of Brookline states, seldom overflows.

As stated in evidence, p. 116, the sanitary condition of the Muddy River water is commonly regarded as fairly good; the only trouble has been that, in common with the ponds above, it has occasionally been subject to growths of algæ, and that, as the name implies, the water is extremely turbid in time of storm.

The water in this river above the Muddy River gate house at Brookline Avenue was intended to be maintained at elevation 11; but the settlement of the banks of the stream and the consequent injury to the shrubs if water were held at this elevation has caused the park department to hold the river between elevation 9.5 and 10.

The Muddy River conduit, designed, as already stated, to take all of the water from the Brookline Avenue gate house to the Charles without passing it through the Fens, is elliptical in section and 9 feet wide by 11 feet high, with bottom at grade —1, Boston base. Its walls are of wood, 12 inches thick, of similar construction to Stony Brook conduit, except that the top, which is above high tide, is an arch of concrete.

The conduit has settled below its original grade from .2 to .4 feet, and has been distorted by the weight of earth above in the same manner but not to such an extent as the 7-foot wooden conduit of Stony Brook.

A length of 650 feet in Brookline Avenue below the Muddy River gate house was supported, in 1887, by a line of posts in centre about 8 feet apart, to prevent further cracking of the concrete key of the top, which could not accommodate itself to the moderate change of about 6 inches in the horizontal and vertical diameters. This line of posts was considered but a temporary expedient, and it was recommended for several years that the conduit be permanently repaired here and the obstruction caused by the posts be removed, but this has not yet been done.

The portion of the Muddy River conduit between the Boston & Albany Railroad and Beacon Street has given still more trouble. In 1884, when some changes in street grade were being made, a trench was excavated beside the conduit, in which to lay a sewer. The trench was not properly braced, and in consequence the 9 by 11 conduit was pushed over into the excavation, and shortly after, under the weight of a gravel

* Estimated population, January, 1903, 26,400, or 5,280 per square mile.

train, a portion of the structure collapsed. This section was immediately patched up, in the most part with concrete, but the conduit is still much out of shape. The material of the conduit is said to be still well preserved.

Although the Muddy River conduit was designed to carry the total flow of Muddy River to the Charles, storm water and all, a short relieving channel, 7 feet by 9 feet, was built from the gate house into the Fens basin, and provided with two 4-foot by 5-foot lifting gates, to take any storm water that the main 9 by 11 conduit might not be able to discharge. This relieving channel has never been used for this purpose of storm overflow.

At the gate house at the head of this conduit, at Brookline Avenue and Audubon Road, tide gates, opening outward, were placed, which prevent the tide from backing up into Muddy River, while salt water from the Charles, flowing freely up this conduit at high water, was admitted to the relieving channel above described as leading into the Fens, by a 3-foot by 4-foot lifting gate. This use of the Muddy River conduit for bringing salt water into the head of the Fens basin has been going on since 1891.

In 1898 a 4-foot by 5-foot flap gate, opening towards the Fens, was placed at the Fens basin end of the 7-foot by 9-foot relieving channel, and the 3-foot by 4-foot gate kept open continuously, in order to admit more salt water to the Fens automatically, and thus avoid the expense and unsatisfactory results of opening and closing the 3-foot by 4-foot gate at high tide by hand.

In 1900 the tide gates in the main conduit were moved up stream, so that more salt water could be admitted to the Fens basin, by thus making possible the use of the two 4-foot by 5-foot lifting gates at the head of the 7-foot by 9-foot relieving channel, in addition to the 3-foot by 4-foot gate.

There is without doubt some salt water in the bottom of Muddy River just up stream from this gate house, for the tide gates designed to keep it out are said to leak.

While it is not intended that any Muddy River water should enter the Fens, it is plain, since Muddy River above the gate house is held at from 9.5 to 10.0, that its outflow will continue until the rising tide reaches a level considerably higher than that at which the salt water begins to enter the Fens. During this time, therefore, which amounts to from half to three-quarters of an hour, with tides of average height all the Muddy River flow must enter the Fens, and even after the tide gates have shut off Muddy River flow, it is plain that the large conduit must contain a considerable admixture of Muddy River water at the moment when the rising tide closes the tide gates at Brookline Avenue, and that, with the beginning of the flow into the Fens, this limited quantity of Muddy River water will be carried in. This would amount to not far from $1.5/24.4$ hours $= 6$ per cent. of the entire flow of Muddy River.

When the Present Fens Basin became Offensive.

Notwithstanding that the storm overflows at the old Stony Brook gate house must have been much more foul prior to 1884 than after the diversion of the sewage to the main drainage works, the general testimony is that there was no particularly offensive pollution of the Fens basin from the time of its construction in 1882–91 until the dry-weather flow or "foul flow" of Stony Brook was discharged into the basin through the commissioners' channel in 1897.

Mr. E. W. Howe, formerly the assistant engineer in charge of park

construction, states that during the fourteen years 1883 to 1897, or from the removal of the foul flow of old Stony Brook to the Charles by the conduit built in 1882 until the extension of commissioners' channel up Columbus Avenue, which by its lower grade brought the dry-weather flow into the Fens basin, the water in the basin was not offensive except at intervals when the portions of the old basin unfilled at that time, lying outside of the park, became so foul that it was necessary to draw them off through the Fens basin. For example, the abandoned channel of Stony Brook received house drainage from an unsewered district near Ward Street, and at times became such a nuisance as to cause complaint, after which the Fens basin would be drawn down, and the filthy water of the stagnant pool drained off into the Fens basin. The effect of this was to kill the fish in the Fens basin, and make its water decidedly foul for several days.

Even after the commissioners' channel began to discharge storm water into the Fens, in 1889, the conditions were not particularly bad, nor did any complaints arise until the dry-weather flow or "foul flow" was diverted from the old conduit to the new conduit, in 1897, and was thus discharged into the Fens basin. The storm overflows of course brought in some dilute sewage, but *the trouble seemed to be then not so much from the overflow of that particular storm as from the foul liquid that had been lying since the last storm in the long conduit between the overflow chamber at Roxbury Crossing and the basin, and that was forced into the Fens by the later overflow.* This pollution would disappear in a few days.

The condition of the water in the Fens basin could not have been very unwholesome up to 1896, when the boats were first put on the Fens basin. An examination by Mr. Howe, in August of 1896, which he recorded in his notes, found the basin "all right."

The worst of the trouble, then, began in 1897. Mr. Howe finds from his notes that the first serious complaint about the condition of the Fens basin was made Dec. 1, 1897. Shortly after this, the basin was drawn to elevation 4.5, and inspected. Mr. Howe noted that he "found no foulness except at the outlets of the two conduits, where there were considerable deposits." "The shores of the pond were clean, except for dead fish which had been killed by sewage."

That there was no serious pollution of the Fens basin until 1897 is further corroborated by Mr. Dorr, chief engineer of the sewer department. In evidence, p. 79, he states that he remembers no complaint as to the condition of the basin prior to the year 1897, and that prior to that time the polluted dry-weather flow of Stony Brook did not enter the Fens. But with the construction of this new commissioners' channel at a level so much deeper than the old, many new sewer overflow connections were made, and the general drainage of the territory entered the new and lower conduit in preference to the old channel and its higher level.

In December, 1897, these deposits in the basin below the outlet of the commissioners' channel were much discussed, and steps were taken to remove them, which resulted in the dredging of 1898.

An appropriation of $25,000 was made by the street department in 1898 to remove these deposits, and this amount was expended by them in outfit and work. A hydraulic dredge was placed in the basin, and material removed by pumping it into the 7-foot conduit, which took it to the Charles River, where it was again dredged up and taken away. Although no accurate survey estimate of the amount of material dredged was made, Mr. Putnam judged that an area (colored blue on the lower part of the map opposite p. 216) from the small island just below the

outlet of commissioners' channel to next bend below gate house was covered, and that from some 15,000 to 30,000 cubic yards were removed.

He made an examination shortly after the dredging was done, and found that within this area much of the bottom had been dredged to elevation 0, while he thought the whole would average dredged to elevation 2.5. The street department did not claim that they had removed all of the deposits that had been brought in by Stony Brook. In the evidence, p. 114, Mr. Putnam states that only one-half * of the mud bank in the Fens basin near the outlet from Stony Brook had been dredged out, and that the area once dredged had been partially filled up again.

Present Condition of the Fens Basin.

When the Fens basin was proposed, boating was expected to be a principal feature. Boats were placed on the basin in 1896, but were little used after the first two seasons, and were withdrawn in 1901, because of lack of patronage.

It is plain that this basin is not now attractive for boating or other park purposes; that in time of storm its surface is occasionally grossly polluted by sewage filth; it is certain that there are now extensive deposits of sewage sludge over nearly the entire bottom of the basin, this deposit being from 4 to 5 feet deep near the outlet of Stony Brook channel, and tapering off to perhaps 6 inches in depth near the Muddy River end, and also to about 6 inches in depth at the Charlesgate end.

Not only does the Fens basin receive much pollution from sewage overflows discharged into the new commissioners' channel in time of storm, but even in dry weather it is not uncommon to see fresh sewage entering the basin from the new conduit.

It is fully established that sulphuretted hydrogen, marsh gas and other obnoxious gases, products of putrefaction, bubble up from its water over these sludge banks near the outlet of Stony Brook in warm weather.

The usual appearance of the water in the Fens in summer is brown or yellow, and after a storm even milky with turbidity. The turbidity, although noticeable over the entire area of the basin, is much more marked at the outlet of the Stony Brook channel, where bubbles are constantly arising from sludge deposits. These deposits, when disturbed, as by the oars of a passing boat, give to the water an inky appearance.

But it must also be said, in advance of much that follows, that, while the present condition of the Fens basin is very offensive to sight and smell, so far as I can learn, it remains to be proved that it is distinctly unhealthful. The immediate vicinity of the water is little frequented, considering its location, more because the water is unattractive than from any disagreeable odor; and it is probable that the odors are never strong enough to be noticed at the nearest houses, located about 400 feet away.

No disagreeable odor is ordinarily noticed, even when in a boat on the basin, elsewhere than at the outlet of the Stony Brook channel, except where there is not a free circulation of air, as, for instance, under the Beacon Street bridge.

In the late summer, small, dirty-looking but otherwise inoffensive patches of green organic growth,† apparently detached from the bottom of the basin, are found floating on its surface.

It is plain, from what has been said in the preceding pages, that the

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* February, 1903, Mr. Putnam, on further consideration, thinks less than one-half was dredged out.

† *Lyngbya*. See Appendix No. 6, p. 325, at (*a*).

present trouble began mainly with the diversion of the dry-weather flow of Stony Brook into the Fens, by reason of the extension of the commissioners' channel up stream, under conditions which diverted the flow from the old channel; and the Boston park department, according to Mr. Putnam, assistant engineer, has proposed to remedy the present conditions, and carry the foul flow, as formerly, directly to the Charles River, by means of a new conduit which should be built, 12 feet in diameter, from the down-stream end of the 17-foot commissioners' channel as far as the old Stony Brook gate house, and thence continued to the Charles River by a larger section of 13½ feet high by 14½ feet wide; this new channel taking the whole ordinary flow of both of the Stony Brook conduits.

This matter has also been very carefully considered by Mr. E. S. Dorr, chief engineer of the Boston sewer division of the street department, in his report for the year 1901, City Doc. No. 40, p. 223, from which we extract the following: —

"The pollution of the Fens ponds by the waters of Stony Brook is a subject which has been the cause of much complaint and correspondence with the park department.

"These ponds have now become practically pools of sewage, a menace to public health, and a common nuisance.

"In order to explain how this deplorable state of things has come about, it is necessary to review a little the history of Stony Brook and the Back Bay Fens park.

"When this parkway was planned, the fact was recognized that the open waterway was a part of the channel of Stony Brook and Muddy River,* and that these two water courses flowing through populous districts could not be expected to run clear at all times; and that it was therefore an essential feature of this kind of a park system to provide a covered channel, through which the flow of these water courses could be turned directly to the Charles River without going through the ornamental ponds whenever such flow was foul; and large covered channels were built for both Stony Brook and Muddy River. At that time the only channel of Stony Brook was the old channel, located in Bryant Street and Parker Street. The gate chamber was built at this point, and a 7-foot circular wooden conduit built from the gate chamber to the river, and gates were so arranged that the flow of Stony Brook could be turned in either direction, as it might be either clear or foul.

"A similar arrangement was made on Brookline Avenue at the parkway, a gate chamber being built here of similar design, and a 9-foot by 11-foot wooden conduit carried down Brookline Avenue and Deerfield Street to the river.

"These provisions were wise, and answered their purpose at the time, the large channel formed by the ponds furnishing an ample outlet for the clear water of freshets, and the covered channels being available for the foul flow caused by small and moderate rainfalls.

"When the Stony Brook flood of 1886 occurred, a commission was appointed . . . and devised a plan, which has been carried out since that date, in part, and which is still in process of construction. . . . No provision was made by this commission for any foul flow channel similar to the one with which the old channel had been furnished. . . . *To the failure of the city to make this provision is due the present condition of the Fens ponds.*† . . . The surface water (of the Stony Brook water-shed) is still conveyed to the brook through the common sewers, and discharged into the brook during rains by means of overflows. Of course some sewage is necessarily mingled with the storm water, and during light and moderate rains the admixture of sewage is large, compared with the rain water.

"Another circumstance which aggravates the condition of things is that *the main sewer in the Stony Brook valley is but little larger than is necessary to carry the dry-weather flow, so that comparatively light rainfalls cause overflows of but slightly diluted sewage into the brook.*

"The consequence of this state of affairs is that the Fens ponds have been growing more and more foul year by year. The water in the ponds is actually

* That the present use of the Fens as a channel for these streams is contrary to the design of Mr. Frederic Law Olmsted is plain from reading his reports. He desired that this have the characteristics of a salt-water basin surrounded by marsh, and that these fresh-water streams be excluded. (J. R. F.)

† Italics are ours.

offensive in warm weather. This is a disgrace to the city of Boston, and a foul blot upon the otherwise beautiful park system. The condition has become so bad that, unless some remedy is applied at once, the whole character of this beautiful water park will have to be changed, a covered channel provided for the brook, and the Fens filled in, thus sacrificing the distinctive characteristic of this part of the park system. . . .

"The effect of these pools of sewage upon property in the vicinity should also be considered. *The Fenway lands are naturally fitted to be developed into the finest residential and hotel district in the city of Boston; but that development is being retarded, and, in my opinion, will be held in check indefinitely, until the Fens ponds can be purified and kept pure.* . . .

"The remedy is a simple one, but not inexpensive. It is to provide the new channel of Stony Brook with a foul-flow or by-pass channel, which will perform for it the same function which the existing covered channels do for the old channel of Stony Brook and Muddy River.

"This office has made a study of what is desirable to build, and has designed a 12-foot by 12-foot covered channel for this purpose, with a gate house to be located at or near the terminus of the Commissioners' channel at the Huntington Avenue entrace of the park and extending to Charles River, substantially parallel with the existing 7-foot channel which connects with the old Stony Brook channel at Bryant Street. This channel will be large enough to carry the flow of Stony Brook during storms whose magnitude does not amount to that of a freshet.

"During freshets the flow of Stony Brook is clear enough to cause no nuisance in flowing through the open channel of the Fens, and flows clear for such a long time after sewer overflows cease that it will sweep out any offensive material that may come down at the beginning of the freshet.

"The gate chamber is designed to be furnished with sluice gates operated by hydraulic rams, which will be set in motion automatically when the flood in Stony Brook reaches a given height. These gates will therefore remain closed during all except freshet times, and all ordinary flow of Stony Brook will be carried by the new channel directly to the river.

"The cost of this channel, including the sluice gate house, is estimated at $300,000.

"*The condition of the old channel of Stony Brook . . . is also a source of pollution to the Back Bay Fens.* The foul flow is of course turned through the 7-foot channel which was provided for that purpose, as has been previously described; but during floods large amounts of sewage sludge which had been previously deposited in this channel, encumbered as it is with interior bracing in many places to keep it from falling in, are necessarily carried over into the Fens ponds. *It is impossible to prevent this accumulation of foul matter in this old stone channel, except by rebuilding the channel and providing proper house sewers* connecting with the intercepting sewers, to carry the drainage of the abutting estates which are too low to drain into the existing sewer systems.

"The estimated cost of rebuilding this channel, together with the pipe intercepting sewers on each side, is $302,000."

Present Condition of the New Stony Brook Conduit.

The Covered Channel. — From personal inspection, I find, as expected, that the structure is excellent throughout, large, well-ventilated, and with no sign of settlement, crack or other structural defect, and clean everywhere above the ordinary water line.

Its great size, 17 feet wide by 15½ feet high inside, makes it a very impressive structure, and, considering its high slope and consequent velocity of upward of 10 feet per second when nearly full, it is capable of conveying an enormous volume of water, 2,000 cubic feet per second, probably equal to a safe delivery from this water-shed, as now developed, of the greatest storm of a century; and in great storms this high velocity will cause it to scour itself clean, if the present heavy material, like cobbles and brickbats, is once cleaned out.

The down-stream half is very easily inspected from a boat, entering from the Fens; but for inspection of the up-stream half, wading boots are necessary.

The present condition below the water line is bad and foul in the extreme by reason of deposits of filthy sewage sludge and other putrescible material.

Sewage Sludge Deposits. — The sewage sludge is found mainly in the down-stream mile, or within the distance reached by salt water; at the lower end it is about 2 feet deep, and tapers out gradually to 6 or 8 inches, or less, in depth.

Mr. Sidney Smith, C.E., during his inspection for sewer inlets, made note of depth of sludge at various points at a time in September following two weeks of dry weather, and reports as follows: —

Beginning at the down-stream end, near the point where the double channel discharges into the Fens, sludge from 23 to 29 inches in depth was found on the bottom of the brick conduit. The blade of an oar forced down into it comes up black and stinking, and gas bubbles up copiously. This deposit appears to be nearly all soft sludge or mud, with little or no sand.

At about 1,129 feet up stream from its outlet into the Fens, near the Willis Street man-hole, this black sludge was found 31 inches deep in the west conduit and 24 inches deep in the east conduit.

At about 2,100 feet up stream from the Fens, near the down-stream end of the large single channel, about 12 inches of this soft sludge, plus about two inches of sand, was found spread over the bottom of the conduit.

At about 3,200 feet up from the Fens, near the Tremont Street man-hole, there was found about 8 inches of the black mud on about 6 inches of sand.

Deposits of Rubbish and Gravel. — At about 6,000 to 7,000 feet up, depending on height of tide in Fens and on volume flowing in Stony Brook, further progress in a boat is prevented by the bars of gravel, brickbats, etc., lying on the bottom; and there is little sludge found except in the pools and eddies caused by these little dams and other obstructions. These heavier materials are not found much below Old Heath Street, 6,036 feet up from the end of the Fens.

Within the down-stream mile the surface of the brickwork at various places near the dry-weather flow line was covered by a foul, adhesive, slimy, greasy coating, one-half inch thick.

During the inspections of Mr. Sidney Smith, and also in the inspections by H. W. Clark, W. E. Spear and C. H. Rooks, many of these deposits of rubbish were noted at from 6,000 to about 10,000 feet up from the Fens; and in the pools formed behind these little dams, fæces, dead cats and other foul material, brought in doubtless in part by sewer overflows, collect and putrefy.

In dry, warm weather, the rich nitrogenous brewery waste adds to promoting the fertility in these culture pools for bacteria; and doubtless the effluent into the Fens is, from this cause, much worse than it would be if the bed of the conduit could be kept clean.

For the three-quarters of a mile of this conduit farthest up stream, or from Boylston Avenue to the present terminus near Green Street, the general condition of the conduit was reported as fairly clean, except for a thin deposit of silt from drainage pumped in during its recent extension. There was little or no gravel, brickbats or rubbish in this upper portion, but the silt or sand was found from 3 to 6 inches deep in some places.

This rubbish has perhaps come from washouts, overflows or accidents, during the long period in which construction has intermittently been pushed up stream, and perhaps from incomplete cleaning up by the contractors in the hurry at the close of a season's work. Possibly some débris of this kind will continue to accumulate until the channel has been completed up to Forest Hills, a few years hence.

With the construction work at an end, the whole channel will then

naturally be cleaned out and freed from this coarse, heavy débris by shovels, scrapers and wheelbarrows, and movable flushing dam and after this the up-stream portion can doubtless be easily kept clean, if the sand overflowing from the catch-basins is occasionally loosened and flushed along, and if a suitable screen, sump and intake chamber is built at its up-stream end.

But in the down-stream half, where the back water from the Fens increases the depth and decreases the velocity, deposits of sand and street wash that escape the catch-basin, mingled with some sludge from the overflow of sewage, will naturally collect; and this will continue to be flushed out and defile the Fens basin in time of storm, unless some other outlet is provided, as discussed elsewhere in this report.

The condition of this covered conduit is doubtless now the worst that it ever has been, and worse than it will be in future, after the construction work is finished and the conduit once well cleaned.

Foul Water entering the New Conduit. — We made four or more fairly complete inspections throughout nearly the entire length of the conduit, in the effort to locate the main source of pollution during dry weather, the most of these inspections being after a period of two weeks without rain. Samples of water for chemical analysis were taken at various points, and at my request the chemist of the State Board of Health inspected the conduit for a little more than 2 miles in length, in order to see the surroundings from which these samples came. The analyses will be found in his report.

I also had a thorough inspection of each inlet to the new Stony Brook channel made by Sidney Smith, C.E., who was resident engineer in immediate charge of building about half of the entire conduit, because of his presumed familiarity with all details.

Although some six to ten pipes or sewer connections were found discharging continuously, the volume from each was very small, and the total less than I expected to find, after noting the condition in the Fens. The following were the most notable instances, and were found after a long period of dry weather: —

1. At a pipe understood to come from the Boylston brewery, an intermittent discharge of about 0.2 cubic foot per second or 90 gallons per minute of hot, dirty water; perhaps mainly engine condensation water.
2. At Columbus Avenue and Centre Street, a large inlet, 51 inches in diameter, a storm-water drain from that portion of the old conduit south of Centre Street, was found discharging at least .05 cubic foot per second, or say 2 to 3 gallons per minute.
3. At Columbus Avenue and New Heath Street the largest and foulest flow, .30 cubic foot per second, equivalent to 135 gallons per minute, was found entering. This came from the old 7 by 10 foot channel which formed the westerly half of the old channel from the Stony Brook valley sewer from New Heath Street to Old Heath Street, and into which the overflow from the Stony Brook valley sewer discharges near this point. It is said at city hall that this overflow is in action most of the time, even in dry weather. We found its odor very offensive, and noticed considerable fæcal matter floating near its outlet On September 2 and September 30, flow estimated by Mr. Spear, .3 cubic foot per second; on November 12, estimated by Mr. Smith, .5 cubic foot per second, equivalent to 225 gallons per minute.

4. At Columbus Avenue and Cedar Street the 30 inch inlet was found discharging about .05 cubic foot per second, say 2 or 3 gallons per minute, that came from the westerly half of the section of the old conduit on the east side of Columbus Avenue, between Cedar Street and New Heath Street; while foul, it was not so offensive as the inflow at New Heath Street.
5. A very short distance below the present gate house, above Roxbury Crossing, the 20 inch pipe in the west wall was found discharging .1 cubic foot per second, or say about 45 gallons per minute. This was not extremely foul.
6. A short distance farther down stream, the 16 by 18 inch brick inlet entering on the west side near the ordinary water level apparently admitted some sewage, although the velocity could not be measured with means at hand. Some fæcal matter was floating near.

Although the whole interior was carefully examined with the conduit well lighted up, no other noteworthy influx of water could be found at these dry times, Aug. 22, Sept. 2 and 30, and Nov. 11, 12 and 14, 1902.

The quantities of pollution found entering at various points in as dry a time as any experienced this year are summed up in the sketch at p. 142, Appendix No. 2.

No rain whatever had fallen for eight days previous to this time, and then only .05 inch. The quantities of water were determined by rough and ready methods, mostly with surface floats or weighted rod floats, by engineers very familiar with making such estimates.

The Open, Walled Channel of Stony Brook.

I have personally inspected this from a point above the fork in the railroad line a few hundred feet south of the Forest Hills station, following the stream all the way down to Green Street, the present downstream end of the open channel; and in this distance of only about a mile have seen a gradual transformation, during dry, warm weather, from a clear, attractive, country brook, flowing over a clean bed between grassy banks, to a moderately dark, turbid, dirty stream, flowing over a foul bed between unsightly banks.

House building in this district has preceded sewer construction, and a new main sewer is being carried in one of the haunches of the Stony Brook conduit arch, and it awaits the extension of this conduit for three-quarters of a mile before there can be much relief. This, in the general order of things, will come within the next two or three years, or before the time the proposed dam could be built.

Down as far as near Lotus Place, the small amount of pollution that enters the open channel has little effect on the appearance of the stream, but below this point its appearance soon changes. Some house drainage can be easily seen entering the open channel at almost any time, and a close inspection at the base of the loose walls when the water is low reveals others. At the Waldberg brewery I found sundry drips and leaks coming through the wall, and at one time noted a cubic yard or more of malt hulls scattered in the bed of the stream just down stream; and I have found the odor of beer very apparent in some of the samples of water collected below that point for chemical analysis.

Below the Washington Street bridge the bed of the brook is at times very foul; and farther down, near Green Street, the water appears more discolored, and the bed of the open ditch more offensive.

The early extension of the covered conduit to Forest Hills is very desirable.

Purification of the Water of the Fens Basin by Dilution and Renewal.

The fact that some pollution of the Fens basin is probably unavoidable, and that some means must be found of changing the water of the basin to prevent this pollution from making the basin offensive, makes it important to study the methods of dilution and renewal that have been followed in the past; and, in order to understand why this method of taking care of the pollution has failed for a few years past, it is necessary to know not only the amount of pollution but also the degree of dilution, and to follow these questions through not only the recent failures but also through the earlier years of the Fenway park when such means were successful.

Some allowance must be made for the public having become more critical from year to year as more important buildings have been built in its neighborhood.

In the previous pages it has been made clear that, in the period from 1882 to 1896, the condition of the Fens basin was in general such as to cause no serious complaint. That in this period sewage overflows did occasionally enter and were soon absorbed or removed, apparently proves that not only was the dilution at that time sufficient to take care of the ordinary pollution, street wash and surface drainage that entered (the dry-weather flow of brook did not enter), but was ample to take care of the much larger amounts of pollution caused by the storm overflows of sewers brought into the Fens basin through the old, and later through the new, channel of Stony Brook.

The dilution of the water in the basin was first accomplished in 1882 by partially emptying and refilling, to the extent of a foot in depth, with water from the Charles River, taken in at the old Stony Brook gate house, through the old 7-foot wooden conduit, and then, as the tide dropped in the Charles, permitting the basin to drain down again to its former level through the tide gates of the Beacon Street weir.

The new salt water was admitted through a 4 by 5 foot lifting gate, connected with the 7-foot conduit, at a point just down stream from the tide gates in this old Stony Brook gate house. When the basin became foul, this gate was opened and closed by hand at every tide, at such times of night or day as was necessary to take advantage of the tide.

Just outside from the Fens basin, there were certain pools left stagnant while the marsh lands were in process of being filled up and graded. These pools received some pollution, and at times became unsightly or offensive, and it was possible to empty these by drawing down the Fens basin.

When these pools became foul, or when the water in the basin itself became too foul, by reason of sewage overflows in time of storm, to become quickly purified, by drawing and refilling a foot at a time, as already described, the basin was almost wholly emptied all at once, by pulling off the flashboards and taking out the stop plank at the Beacon Street weir at low tide, and thus drawing the basin level down to elevation 1.5 or 2.

By this means much greater velocities in the narrow channels were created than by the flow that could be discharged over the Charlesgate weir. It is the opinion of the engineers formerly in charge of the Fens basin that, had this practice of almost completely emptying the basin been continued, the deposits in the Fens except near the outlets of the

Stony Brook conduits where the currents through the basin cannot reach would not be so large as now found.*

This arrangement served very well so long as the basin extended no farther up than the present outlet of the new Stony Brook channel; but obviously no efficient circulation of the water in the long, narrow channel between the Stony Brook gate house and the Brookline Avenue gate house could be effected by taking this salt water in at the old Stony Brook gate house and letting it out again at the Beacon Street weir.

Consequently, when the Muddy River conduit and gate house were built, in 1883, an arrangement similar to that at Stony Brook gate house was made, as previously explained, by which salt water from the Charles could be put into the Fens at high tide at the Brookline Avenue end.

In other words, a 3 by 4 foot gate was placed in a channel leading from the Muddy River conduit to the Fens; and the Muddy River tide gates were located up stream from this 3 by 4 foot gate. And, after the completion of the Fens basin to Brookline Avenue in 1891 permitted its use, salt water from the Charles was admitted to the Fens at high tide through the Brookline Avenue gate house, in addition to the amount that was introduced under similar circumstances at the Stony Brook gate house.

Thus, from 1891 until late in 1896 the water in the Fens basin was kept in a tolerably satisfactory condition by the occasional admission of a foot in depth of salt water from the Charles at the old Stony Brook gate house and at the Muddy River gate house, and by occasionally drawing the water in the pond almost completely out at Beacon Street and refilling with new sea water.

It must be understood that in this period the water was not admitted at every tide, as now, but was only drawn down and refilled at intervals when required. Further, in that period the basin was not foul, and even in December of 1897, when the deposits were found at the outlet of the new Stony Brook conduit, the shores elsewhere than at the outlet of the two Stony Brook channels were reported clean.

†After December, 1897, in the effort to improve the appearance of the water and incidentally to effect economy and dispense with so much manual labor, the methods previously employed were changed, and the partial emptying and refilling made automatic by means of flap gates. Mr. Putnam, assistant engineer, Boston park department, reports that conditions have never been so bad since as they were immediately before the automatic gates were put in. Salt water was no longer admitted through the 4 by 5 foot gate opening at the Old Stony Brook gate house, but all sea water that entered the basin passed through the 3 by 4 foot gate at the Muddy River gate house; according to the statement of Mr. Putnam, in the evidence, p. 117, a rise and fall of 12 inches was maintained.

Obviously, the height of rise and fall is an accurate measure of the quantity of water admitted and withdrawn, *but is no proof of circulation* until we are assured that it goes out at a different place from that at which it comes in, as will later be shown.

This 12 inch rise and fall did not prevent the basin from becoming offensive; and the fluctuation of 12 inches was reported increased in August, 1900, to 18 inches, by increasing the gate area through which the salt water could flow into the Fens from the Muddy River conduit,

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* But, on the other hand, Mr. Putnam reports that in January, 1898, the mud or sludge deposit averaged more than 3 feet deep over an area of 6 acres near Stony Brook outlet, and extended over a large portion of the remainder of the pond; and that this deposit had formed while the original method of flushing was still in use.

† In 1898 the engineers of Boston park department relieved the city engineer's department in the supervision of the Fens basin.

by the use of the two 4 by 5 foot lifting gates in the relieving channel. The tide gates were moved up stream to a point above these two gates. Mr. Putnam informs me that a 6 by 6 foot flap gate was substituted for the 4 by 5 foot gate at this time.

The additional gate area thus made available was utilized by opening the 4 by 5 foot gates except during the fall of 1900, and in November, 1902, when one of the gates was opened half way. Just previous to this, our recording gauge indicated that a mean depth of 0.72 feet was admitted to the basin, and comparison with the subsequent gauge charts show that this partial opening of this 4 by 5 foot gate did not materially increase this amount.*

But for the fact that it is impossible to open either of the two 4 by 5 foot gates farther, Mr. Putnam states that the experiment of admitting more water by raising the basin to a higher elevation would have been tried. The lifting apparatus on the gate in the Stony Brook gate house was broken and not repaired, and until repairs are made no water can be admitted there.

After November 11, when flashboards were pulled off at Beacon Street weir and the pond permitted to drain down lower than before, a mean depth of 1.35 feet was admitted.†

This arrangement gives a greater fluctuation than before; but, on the other hand, the drawing down, which is necessary to effect this, exposes the foul sludge deposits, and obviously not quite so large a quantity of new sea water is admitted for a given depth at a low elevation of pond as at the grade at which the basin was previously carried.

The pond is not now drawn completely off, and the entire contents renewed as formerly, but two 4 by 5 foot gate outlets have been provided for this in the new masonry at the Charlesgate.

A concrete dam was built in 1900 behind the arches of the outlet of the Fens at the Charlesgate, to replace the old weir at Beacon Street, and thus make the present unsightly 100 feet of pool between Beacon Street and the Charles River a part of the Fens basin. The crest of this concrete dam was placed at grade 6.5, and flap gates were hung above the crest to prevent any flow from the river sufficient to hold the Fens basin up to elevation 7 before releasing any of the water behind them. This dam cannot, of course, be used until the 7-foot conduit is extended to the face of the river wall, else, with the removal of the present dam, the "foul flow" of the old conduit would back up into the Fens basin. At present, the flow of the old conduit and the discharge from the basin over the Beacon Street weir passes this new dam by the two 4 by 5 foot gate openings above mentioned, through which the tide freely ebbs and flows.

When we consider that *the leaks at Brookline Avenue let 60 per cent. of the new water admitted run back without circulating*,‡ it is clear that, although the amount of pollution entering the Fens basin is much greater than before 1898, not as much salt water is apparently admitted from the Charles as before, and no complete emptying and renewal of the water is now attempted.

From the foregoing investigation we learn that the Fens basin, although receiving sewer overflows and street wash, was not offensive

* Mr. Putnam states, February 23, that after fastening the tide gates open the rise of the pond increased to 8.5 regularly, which is the danger line for the plantings.

† Mr. Putnam states the reason for reducing the daily rise and fall from 18 inches was that the more turbid water was less unsightly than the dirty shores exposed by drawing down, and that to get 18 inches below 8.5 requires removal of flash boards at Beacon Street.

‡ Mr. Putnam writes me that he considers that this amount of leakage must have been temporary, and probably due to some of the weights having fallen off from the flap gate.

for about ten years prior to 1897; that since this time it has been very offensive; and that at about that time two very important changes took place: first, the pollution was increased by bringing into it, continuously, all the foul flow from Stony Brook; second, the volume of dilution was diminished * by abandoning the use of the gate in the Old Stony Brook gate house, and by emptying the basin occasionally.

For the Future, if Proposed Dam is built. — The opinion was freely expressed at the hearings, by engineers and others, with no dissenting voice, that, if the Charles River is maintained at a constant level of grade 8, some circulation must be provided to remedy unavoidable pollution, and to keep the basin in a wholesome condition.

Mr. C. E. Putnam, assistant engineer of Boston parks, states this in his evidence, p. 115; and he further says that, if the basin were thoroughly and properly cleaned out and all sewage diverted, there would not be anything like the amount of circulation required that is now needed, and possibly not any.

Mr. E. W. Howe, for many years engineer in immediate charge of Boston parks, also believes that, in view of past conditions of the Fens basin, when no dry-weather flow was admitted, some circulation will be necessary in this basin if the Charles River dam is constructed.

In the report of Percy M. Blake (evidence, p. 207) the idea of artificial circulation in the Fens is advanced, and he estimates the cost of a pumping plant and special waterways at $50,000, and an annual cost of operation at $6,000.

It appears to me that some circulation must be provided for, and that this can be best accomplished without pumps and their expensive maintenance, by drawing off some definite amount of water continuously through a weir located near the present bridge at outlet of new channel of Stony Brook, which should discharge into the conduit through which I propose that the foul flow (dry-weather, ordinary flow) of Stony Brook from the new channel is to be taken into the old gate house, and thence down to below the site of the proposed dam by the large marginal intercepting channel elsewhere described.

Measurements of Actual Circulation of Water in Fens Basin, October and November, 1902.

We began this work by setting a clock gauge at the old Stony Brook gate house over a chamber which is in free communication with the Fens basin, and rises and falls in precise conformity thereto.

This clock gauge measured the height continuously, throughout the twenty-four hours, from October 22 until after November 10, and it was quickly found that the daily rise and fall, instead of still being 18 inches, as implied in the evidence, p. 117, was only about half this amount.

The form of the curves of rise and fall, when closely examined, suggested leakage through the gates; and arrangements were then made for measuring the inflow during high water at the Brookline Avenue gate house, and also for measuring the leakage backward through this gate during the period of low water.

Measurements of inflow were made by means of observing the head acting on the orifice through which the water entered, having first carefully inspected this orifice and measured its area. The leakage backward was measured by means of vertical rod floats within the channel between the sluice gate and the swinging gate.

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* Mr. Putnam believes that, under the care and methods of the park department, the diluting volume was increased.

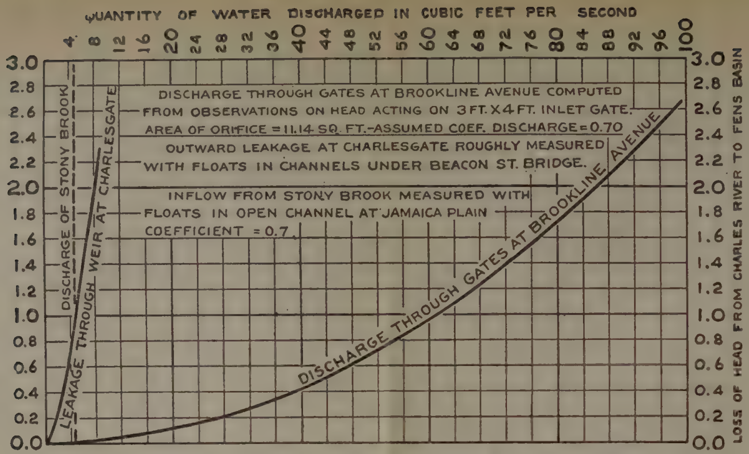


DIAGRAM OF FLOW INTO THE FENS BASIN FROM CHARLES RIVER AND STONY BROOK.

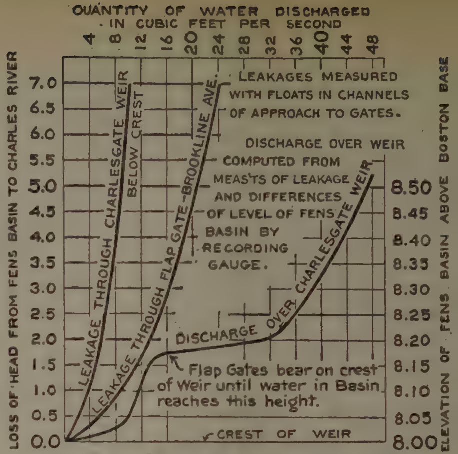


DIAGRAM OF FLOW FROM FENS BASIN TO CHARLES RIVER

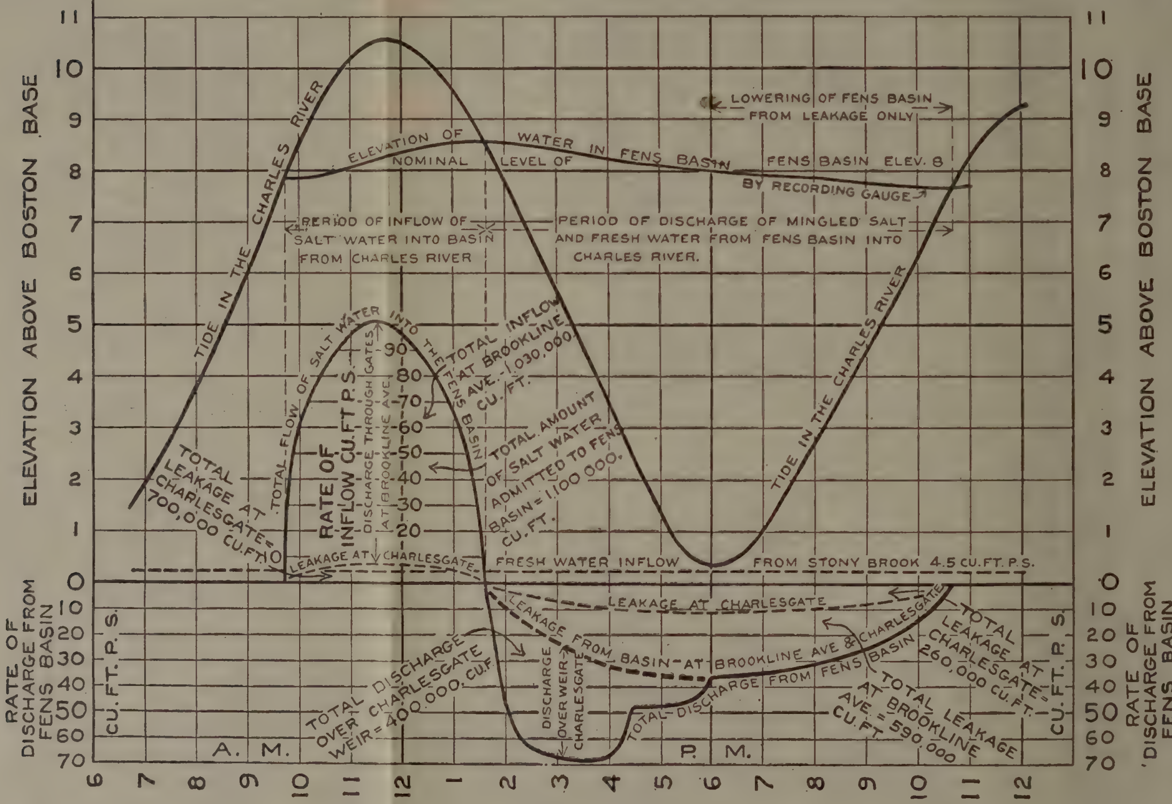


DIAGRAM SHOWING DILUTION OF WATER OF FENS BASIN

BY THE ADMISSION OF SALT WATER AT BROOKLINE AVE. AND DISCHARGE AT CHARLESGATE

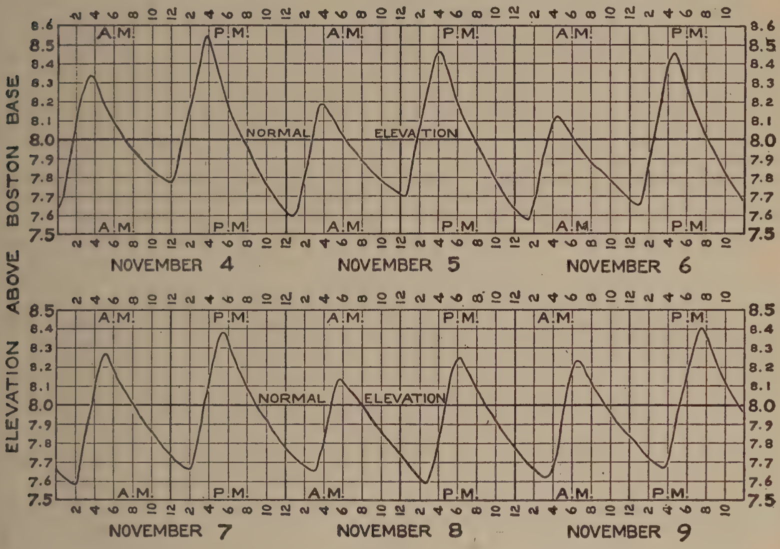
NOVEMBER 1. 1902.

Note that, of the total inflow of 1,030,000 cubic feet of salt water at Brookline Avenue, all of which should have flowed through the basin and discharged at Charlesgate, 590,000 cubic feet, or 60 per cent., leaked back into the Charles at the point of admission at Brookline Avenue without passing through the basin. This leakage, with that through Charlesgate weir, pulled the basin down below crest of weir sooner than if all the water had discharged over the weir, and shortened the period during which circulation could otherwise have been maintained by discharge over Charlesgate weir to about 4½ hours.

Other measurements of inflow, somewhat rough, were made by means of floats (weighted vertical rods) in the vicinity of the Charlesgate weir; and from these it was found that there was a very perceptible leakage inward at this point during the few hours when the water level in the Charles is above that in the basin.

Corresponding measurements of inflow were made by means of floats, from which it was found that there was very considerable leakage outward through these gates at Beacon Street after the time when the water in the Fens basin had fallen below the crest of the overflow, at which point leakage was supposed to stop.

A computation of inflow and efflux, based on the records of the gauge which showed the range in water level of the basin continuously, taken



RISE AND FALL OF WATER IN FENS BASIN

FROM NOVEMBER 4 TO NOVEMBER 10 1902

FROM CONTINUOUS RECORD OF RECORDING GAUGE AT OLD STONY BROOK GATE HOUSE.

in connection with the area of surface of basin, served to confirm these float measurements and other computations; and, as a whole, the measurements checked up so thoroughly as to leave no doubt of their substantial accuracy.

It was found, in brief, by these measurements, that, although about 1,000,000 cubic feet of new water from the Charles was admitted to the Fens basin on each tide at the Brookline Avenue gate house, *the leakage of the swinging gate (or "flap gate") at Brookline Avenue was so excessive that 60 per cent. of the water taken in at high tide leaked backward on the succeeding low tide without ever passing through the Fens basin.*

It was found that the total amount of new water from the Charles admitted to the Fens basin and circulating through it amounted to an average of about 15 cubic feet per second per twenty-four hours (a small portion of this 15 cubic feet per second was water from Muddy River); while the average inflow of the polluted Stony Brook water, during the same period, averaged about 5 cubic feet per second.

The proportion of salt water over fresh water admitted was therefore about 3 to 1.

The diagrams show the daily fluctuation in water level, and also exhibit the relative height of water in the Charles and in the basin on Nov. 1, 1902, together with the rate and amount of flow in either direction produced by these differences in level.

Depth of Water in Fens Basin. — Depth of Sludge.

For determining the volume of water contained in the basin, a new series of soundings was made, and the depths at all points are shown on the folding map inserted opposite the next page.

Measurements of the depth of the deposit of sludge were made at the same time, and are presented on the same map; but the method of measurement does not permit of defining the bottom of the sludge or the line between the recent deposit and the older deposit with any great precision, and, although this measures up at about 70,000 yards, I am not strictly positive that it exceeds 50,000 cubic yards.

The method followed for measuring the depth of water on top of the sludge was to use a graduated rod, to the bottom of which a broad disc was attached, so that this should be prevented from penetrating the very soft semi-fluid surface of the sludge; and immediately afterward another graduated rod, with blunt end 1 inch in diameter, was forced down through this sludge until a harder substratum was distinctly felt to impede the further penetration of the rod.

It was commonly possible to notice a distinct difference in the character of the material, as the bottom was reached, in the grating of the shells or gravel against the bottom of the rod as this was partially revolved.

A subsequent effort was made to determine this depth of sludge with greater precision, by means of forcing down a piece of 2-inch pipe into the hard material at the bottom, and lifting this pipe out of the water and carefully forcing out the core of mud within the pipe by means of a piston. It was found, however, that the upper part of the sludge compressed so readily that much of the water was squeezed up and escaped past the piston; and freezing weather finally interfered with making such extensive experiments as had been intended. But the dozen or twenty samples obtained tended to confirm the depths shown by the sounding rod.

The results of all these measurements are given on the folding map inserted opposite this page.

It will be noted that they show that the basin is now filled up to about one-fourth of its entire capacity with sludge, or that there is one-third as much of foul sludge as there is of water in the basin, and that the amount of sludge now in the basin is probably three times as great as that dredged out in 1898.

I believe that all of this should be cleaned out, whether the proposed Charles River dam is built or not, after the proposed new channel for diverting the foul flow of Stony Brook has been made complete to the Charles River.

If the dam and the marginal conduit along the Charles are not built until sewage is removed from Stony Brook, a similar deposit will probably occur at whatever point the polluted fresh water is discharged into salt water; but by locating the point of discharge where considerable current exists, the bad effects will be lessened. Various means are available for lessening the present offensive conditions, such as repairing leaky circulating gates, excluding salt water by a weir from

PRESENT CONTOURS OF BASIN

(TOP OF SLUDGE OR MUD)

ABOVE BOSTON CITY BASE

Elevations of water surface determined by automatic tide gauge located at old Stony Brook gate house. Depth of water measured by rod with foot piece 3 in. square, care being taken not to press this into the mud.

These present marsh areas in the Fens were graded at 8.5 to 9.0 in order to form temporary storage for floods from Stony Brook during high tide. They were partly filled on old flats at about grade 3 with material dredged from site of present basin and partly cut down from old marsh at grade 10 to 11.

CONTENTS OF BASIN		
	Water	Sludge
Section of Basin	Contents between Present Bottom and Grade 8 cu. ft.	Volume of Deposit of Sludge cu. ft.
A to B	342 000.	33 800.
B to C	2 338 000.	735 600.
C to D	743 600.	635 000.
D to E	1 668 800.	392 600.
E to F	659 900.	81 800.
Stony Brook Conduit	406 700.	
Total	6 159 000.	1 878 800.

THE FENS BASIN

BOSTON, MASS.

CONTOURS AND DEPTH OF SLUDGE

FROM SURVEYS FOR

COMMITTEE ON CHARLES RIVER DAM

BY R. W. ARMSTRONG

NOVEMBER AND DECEMBER 1902

Outline from plan for the improvement of the Back Bay dated December 31, 1890 in office of City Engineer, Boston. Park Department.

DEPTH OF DEPOSIT OF SLUDGE

NOTE. These depths of sludge were determined by first measuring depth to top of sludge and then forcing a rod with blunt end 1 inch in diameter down through sludge until with a force of say 10 lbs it would penetrate no further. Commonly at about the limit of penetration the grit of shells or gravel against bottom of rod was very noticable.

AREA SHADED IN BLUE DREDGED IN 1898

Quantity not accurately measured. Supposed to have been between 15000 and 30000 cu. yds. Appropriation of $25,000. expended on outfit and work. Intention was to dredge to original bottom at grade 0. Therefore much shoaling has apparently taken place during the past four years.

HELIOTYPE CO BOSTON

new Stony Brook channel, immediately dredging basin, immediately building a connecting conduit only about 400 feet long from end of new channel at weir just proposed, under the Stony Brook bridge, down into the old 7-foot channel, etc.; but the one real remedy is, *remove the present sewage and pollution from Stony Brook by means of sewer extensions.*

JOHN R. FREEMAN.

Loss on Ignition of Samples of Mud from Bottom of Fens Basin, received from Dr. G. W. Field.

[See Appendix No. 6, Biologist's Report.]

Number of Sample.	Loss on Ignition (Per Cent. by Weight).	Number of Sample.	Loss on Ignition (Per Cent. by Weight).
4 A,	9.34	7 C,	10.88
5 A,	10.06	7 D,	5.11
5 B,	10.39	7 E,	7.72
8 B,	5.41	8 C,	7.29
7 A,	8.77	8,	11.54
7 B,	13.95		

APPENDIX No. 4.

CHEMIST'S REPORT,

CONCERNING

THE PRESENT POLLUTION OF THE CHARLES RIVER BASIN AND ITS TRIBUTARIES,

AS SHOWN BY CHEMICAL ANALYSIS, AND THEIR CAPACITY TO DISPOSE OF POLLUTION WITHOUT THE PRODUCTION OF OFFENSIVE ODORS OR UNSANITARY CONDITIONS; ALSO NUMEROUS BACTERIAL COUNTS ON SAMPLES OF THESE WATERS MADE AS AN INDEX TO ITS CONDITION AND TO THE CHANGES GOING ON IN IT.

By HARRY W. CLARK.

BOSTON, MASS., Dec. 18, 1902.

JOHN R. FREEMAN, C.E., *Engineer to Committee on Charles River Dam.*

SIR: — I make the following report of the investigations upon which I have been engaged for the Charles River dam committee since the beginning of September.

SCOPE OF INVESTIGATION.

This work was undertaken in order to learn as much as practicable, within a limited time, regarding the character of the water now filling the Charles River from Watertown dam to Craigie bridge at high and low tide, of the sewage and drainage entering this portion of the river and of the mud banks exposed at low tide, together with similar information in regard to the water flowing in the river at and above Watertown dam, and the drainage and wastes entering this upper section of the river. This was done to enable us to compare one with the other, and thus be able to foretell with considerable accuracy the conditions which may prevail if a dam is built at or near Craigie bridge, and the present tidal estuary changed to a fresh-water basin.

The following report, then, relates largely to the present condition of the waters of the Charles River basin and its tributaries, as shown by chemical analyses, and to the capacity of the river as it is at present to dispose of the pollution received, compared with its capacity if the salt water is practically eliminated and the basin filled with fresh water.

The work was begun about Sept. 1, 1902, and has been carried forward as rapidly as possible, in order that it should be well advanced before winter set in. The autumn was comparatively warm and dry, and hence favorable for our studies. I have supervised the work of

collecting and analyzing samples, and sought, through personal inspection, to become familiar with the localities at which they have been collected. Repeated samples have been taken at many points covered by the investigation of the river and its tributaries, in order to guard against accidental or abnormal conditions; and samples have been taken at a large number of locations, at different depths, and under nearly all conditions of tide and wind, as the tables will show, in order to obtain entirely fair results. About six hundred and fifty samples for chemical examination have been collected and analyzed during the progress of this work, these samples including fresh and salt water, sewage, drainage, mud and sand. Many bacterial determinations have also been made.

To study also as thoroughly as the limited time would permit all parts of this problem, and especially such as could not be satisfactorily answered by the examinations, observations and analyses mentioned, I have planned and supervised much experimental work; and more than four hundred additional partial or complete sanitary chemical analyses have been made in the course of these experiments, together with about two hundred bacterial determinations. In a general way, all this work has been undertaken to answer as clearly as possible the following questions, submitted by you: —

"1. What is the character of the water which now fills the basin?

"2. How does it compare with the unpolluted ocean water?

"3. Does the analysis of samples indicate that the ebb and flow of the tide promptly renew the water of the basin, or does much of the same water surge back and forth day after day, all the time receiving the pollution incident to a crowded harbor until gradually forced seaward by the upland water?

"4. Is the water in the basin continually active in digesting or oxidizing and rendering innocuous the pollution that comes into it?

"5. What is the character, from a chemical point of view, of the pollution that enters the Fens basin and the Charles basin?

"6. What is the character of the upland water of the Charles River as it enters the basin over Watertown dam, and its quality as shown by chemical analysis, in comparison with that of ordinary river waters of eastern Massachusetts? How badly is it polluted by organic matter, factory wastes or otherwise? Is it already loaded with about all the pollution that it can dispose of? How much additional pollution can it receive without becoming offensive?

"7. How is the capacity of this water to dispose of pollution through chemical activity affected by stagnation, as of a pond, instead of such motion as is found in a steadily flowing river?

"8. Given equal volumes of salt water and fresh water, which can receive the largest percentage of sewage without offensive or unsanitary conditions being caused? With which, salt or fresh, will there be the smaller probability of offensive odors or foul deposits of sewage sludge on the bottom?

"9. Supposing the dam is built and the basin is maintained at nearly constant level, is it better that this basin should be filled with salt water from the harbor, periodically renewed, or filled with the fresh water of the upland Charles and the harbor water excluded?

"10. How rapid is the diffusion between a stratum of salt water and an overlying stratum of fresh water?

"11. What is the probability of the mud banks disappearing by bacterial and chemical action, thus doing away with the necessity of dredging?"

It would have been impossible to take up all these questions and answer them fully, especially in the limited time allowed for this investigation; and many were not asked until the work had progressed for a considerable period. I have been able, however, to make such studies that satisfactory answers to many of them will, I think, be found in the following pages, and an accumulation of data that will at least partially answer the remainder.

Quality of Water found in Charles River Basin.

The first subject taken up was the determination of the present condition of the Charles River basin or tidal estuary, the Fenway basin and the Charles River at the lowest Watertown dam, in regard to sewage pollution. The Charles River basin in this report includes the water area from Craigie bridge to Watertown dam, and this has been studied during the past three months quite thoroughly. These studies have included observations of the appearance of the water of the basin at different localities and at all stages of the tide, and observations of the physical characteristics of the water, — that is, its color, odor and degree of turbidity, — together with chemical analyses to show the amount of organic matter present, and also bacterial analyses. Samples have been collected of the surface water and of water from different depths to the bottom of the basin in many localities, and at both high and low tide. Samples of the water entering the basin from Stony Brook and the Fenways have been collected upon different days, and examinations made of the water entering from various sewer overflows and drains. Studies have been made of the river at low tide, in respect to the banks of mud, sand and gravel then exposed, and many samples from these deposits have been analyzed and experimented with.

As a result of these examinations, I find that the larger portion of the lower part of the estuary at the present time contains at high tide a body of salt water with a slight but fairly even admixture of fresh water, the proportion of fresh water increasing towards the upper portion of the basin, as shown clearly by tables Nos. 1–13 inclusive. The salt water coming into the basin from the harbor is found by chemical analysis to be fairly low in organic matter, contains a comparatively small amount of free ammonia — although much greater than the amount present in pure sea water — and free oxygen is present at all depths. The main portion of this water contains at the present time from two to three times as much organic matter as pure sea water, as shown by the analysis of a sample of water* collected off the Boston Lightship, six miles from Boston Light.

The waters of practically the entire estuary at the present time are, under ordinary conditions and at high tide, of a fairly attractive appear-

* The following analysis is of a sample of sea water collected off the Boston Light-ship about six miles easterly from Boston Light, near surface, on Nov. 11, 1902: —

[Parts per 100,000.]

Turbidity.	Sediment.	Color.	Odor.	Ammonia.				Chlorine.
				Free.	Albuminoid.			
					Total.	Dissolved.	Suspended.	
V. slight.	Slight.	.00	Distinctly brackish.	.0012	.0068	.0060	.0008	1813

ance. Local pollutions occur, but these are not noticeable over any considerable area except at times of storm, when large areas are often discolored and of an offensive appearance because of these pollutions, especially at low tide.

The tables following show the various locations and depths at which many samples were collected for this study, together with results of analyses, etc., including many dissolved oxygen determinations.

Studying in detail the quality of the waters of the estuary, as shown by these various analyses of samples, we find that there is quite a regular increase of organic matter as the proportion of fresh water increases, — this proportion being indicated by the chlorine determinations, — the smaller the amount of chlorine the greater the proportion of fresh water, — and that there is also a larger free ammonia content as the proportion of fresh water increases. This is particularly noticeable at low tide, when the fresh water is prominent in the river (see series of September 16 and October 10), but it is also very noticeable at high water (see series of October 6 and October 10).

Interpretation of Analyses.—The chemist's most direct method of detecting the degree of pollution of water by nitrogenous bodies is by the determination of the so-called "free and albuminoid ammonia." A certain percentage of the organic matter present in a water can be measured by a method of analysis which gives the "albuminoid ammonia." If the organic matter in the water has undergone decay, ammonium carbonate or "free ammonia" will have been formed, and this can be distilled and measured.

The nitrogenous bodies in water come from both animal and vegetable life, however, and hence a water may contain considerable free and albuminoid ammonia, and yet be free from harmful pollution,—that is, free from the products of the life and decay of animal matter. This difference between animal and vegetable matter the chemist can detect by other indirect methods of analysis. In the present study we know that any increase in free and albuminoid ammonia in the salt water of the harbor and the estuary above that in pure sea water must come very largely from sewage pollution. Much of the organic matter in the waters of the upland Charles, however, is absorbed by the water from vegetable matter on the water-shed. Practically all the increase in the organic matter in the upland river water from Riverside to Watertown dam is from sewage or factory pollution. As an index of the varying amounts of free and albuminoid ammonia, etc., in sewage and in an exceedingly satisfactory water supply, the following can be quoted: (1) the average sewage of the city of Lawrence for the year 1901, as shown by about two hundred and twenty-five analyses; and (2) the average analysis of the water supply of the metropolitan district of the State, as shown by twelve monthly analyses of the water supplied to the State House.

[Parts per 100,000.]

	Ammonia.			Chlorine.	Oxygen Consumed.
	Free.	Albuminoid.			
		Total.	In Solution.		
Lawrence sewage, ...	4.5400	.7500	.3500	10.03	4.51
Metropolitan water supply, . . .	0.0013	.0158	.0142	0.30	0.42

TABLE NO. 1.—*Charles River Basin, at High Water, from Early Ebb Tide to Mid Ebb.—Sept. 4, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.				Chlorine.	Oxygen Consumed.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.						
					Total.	Dissolved.	Suspended.				
1.45 P.M.,	Slight.	Slight.	.14	.0320	.0244	.0228	.0016	1250	3.30	Surface.	At upper Western Avenue bridge.
1.45 P.M.,	Slight.	Cons.	.10	.0304	.0240	.0188	.0052	1425	3.58	7 feet.	At upper Western Avenue bridge.
3.15 P.M.,	V. slight.	Cons.	.05	.0328	.0208	.0168	.0040	1570	3.40	Surface.	At Cottage Farm bridge.
8.15 P.M.,	V. slight.	Cons.	.05	.0312	.0204	.0176	.0028	1560	3.50	6 feet.	At Cottage Farm bridge.
2.35 P.M.,	V. slight.	Cons.	.05	.0300	.0180	.0176	.0004	1540	3.44	Surface.	At North Harvard Street bridge.
2.35 P.M.,	V. slight.	Cons.	.05	.0324	.0200	.0184	.0016	1530	3.42	11 feet.	At North Harvard Street bridge.
4.05 P.M.,	Decided.	Cons.	.10	.0340	.0296	.0192	.0104	1480	3.54	Surface.	At third pier of Harvard bridge from Boston end.
4.05 P.M.,	V. slight.	Cons.	.04	.0316	.0204	.0152	.0052	1600	3.54	2½ feet.	At third pier of Harvard bridge from Boston end.
4.15 P.M.,	V. slight.	V. slight.	.04	.0288	.0164	.0152	.0012	1600	3.54	Surface.	At middle of Harvard bridge.
4.15 P.M.,	V. slight.	Cons.	.05	.0316	.0168	.0132	.0036	1620	3.52	6 feet.	At middle of Harvard bridge.
4.20 P.M.,	V. slight.	V. slight.	.05	.0312	.0180	.0140	.0040	1590	3.52	Surface.	At twentieth pier of Harvard bridge.
8.50 P.M.,	Decided.	Cons.	.05	.0252	.0192	.0144	.0048	1490	3.28	Surface.	Forty feet from outlet of Muddy River.

High tide at 12.41 P.M.

TABLE No. 2.—*Charles River Basin, at Low Water and Beginning of Flood Tide.—Sept. 10, 1902.*

[Parts per 100,000.]

Time of Collection.	Ammonia.		Chlorine.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Free.	Albuminoid.				
11.35 A.M., .	.0360	.0168	1520	50.3	Surface.	Just below Stony Brook and Fens outlet.
11.40 A.M., .	.0356	.0156	1528	–	1 foot.	Just below Stony Brook and Fens outlet.
11.50 A.M., .	.0368	.0164	1528	53.3	3 feet.	Just below Stony Brook and Fens outlet.
12 M., . .	.0356	.0160	1562	–	6 feet.	Just below Stony Brook and Fens outlet.
12 M., . .	.0320	.0172	1630	–	12 feet.	Just below Stony Brook and Fens outlet.
12 M., . .	.0324	.0188	1327	57.4	Surface.	At Stony Brook and Fens outlet.
12.20 P.M., .	.0368	.0176	1570	58.2	4 feet.	At Stony Brook and Fens outlet.
12.40 P.M.,	.0332	.0172	1560	54.9	Surface.	At Cottage Farm bridge.
12.45 P.M., .	.0308	.0164	1635	52.4	12 feet.	At Cottage Farm bridge.

Low tide at 11.16 A.M.

TABLE NO. 3. — *Charles River Basin, at Low Water, Last of Ebb Tide. — Sept. 16, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Bacteria per c. c.	Depth.	Source.
	Turbidity.	Sediment.	Free.	Albuminoid.				Nitrates.	Nitrites.				
				Total.	Dissolved.	Suspended.							
3.10 P.M.,	V. slight.	Slight.	.0045	.0645	.0284	.0361	282.40	.030	.0006	0.84	1,397,300	Surface.	Below Beechwood Avenue.
3.10 P.M.,	None.	V. slight.	.0244	.0320	.0240	.0080	966.00	.032	.0000	1.15	8,500	2 feet.	Below Beechwood Avenue.
3.30 P.M.,	V. slight.	Slight.	.0120	.0610	.0332	.0278	18.88	.030	.0025	1.10	62,400	Surface.	Below Beechwood Avenue.
4.10 P.M ,	Slight.	V. slight.	.1280	.1440	.0980	.0460	583.00	.039	.0008	1.13	210,000	Surface	At Abattoir.
4.20 P.M.,	V. slight	V. slight.	.0092	.0452	.0280	.0172	641.00	.035	.0000	1.00	39,500	Surface.	At upper Western Avenue bridge.
4.20 P.M.,	V. slight.	V. slight.	.0112	.0372	.0336	.0036	746.00	.037	.0000	1.08	11,000	2 feet.	At upper Western Avenue bridge.

Low tide at 4.12 P.M.

TABLE No. 4. — *Charles River, Surface, at About High Tide. — Oct. 6, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	APPEARANCE. Turbidity.	Sediment.	Color.	AMMONIA. Free.	Albuminoid.	Chlorine.	Source.
1.00 P.M., .	V. slight.	Slight.	.33	.0476	.0248	.90	At Watertown dam.
12.45 P.M., .	V. slight.	Slight.	.40	.0476	.0300	11.50	One-half mile below Watertown dam.
2.00 P.M., .	V. slight.	V. slight.	.22	.0448	.0312	445.00	Opposite Watertown Arsenal.
2.15 P.M., .	V. slight.	V. slight.	.10	.0568	.0240	1125.00	Opposite Abattoir.
2.30 P.M., .	V. slight.	V. slight.	.09	.0432	.0220	1248.00	Opposite lower end of Cambridge cemetery.
2.40 P.M., .	V. slight.	V. slight.	.06	.0596	.0176	1498.00	At North Harvard Street bridge.
2.45 P.M., .	V. slight.	V. slight.	.05	.0596	.0176	1540.00	At lower Western Avenue bridge.
3.00 P.M., .	V. slight.	Slight.	.05	.0500	.0196	1540.00	At Cottage Farm bridge.
3.00 P.M., .	V. slight.	V. slight.	.04	.0544	.0180	1555.00	At north end of Harvard bridge.
3.15 P.M., .	V. slight.	V. slight.	.04	.0524	.0164	1575.00	At south end of Harvard bridge.
3.20 P.M., .	V. slight.	V. slight.	.04	.0528	.0156	1615.00	Half way between Harvard bridge and West Boston bridge.
3.30 P.M., .	V. slight.	Slight.	.04	.0536	.0188	1625.00	At West Boston bridge.

High tide at 2.24 P.M.

TABLE No. 5. — *Charles River, at About Low Tide. — Oct. 10, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	APPEARANCE. Turbidity.	Sediment.	Color.	AMMONIA. Free.	Albuminoid.	Chlorine.	Depth.	Source.
11.15 A.M., .	None.	V. slight.	.15	.0344	.0296	1010	Surface.	At lower Western Avenue bridge.
11.20 A.M., .	None.	V. slight.	.10	.0368	.0192	1048	1 foot.	At lower Western Avenue bridge.
11.20 A.M., .	None.	V. slight.	.07	.0360	.0164	1280	7 feet.	At lower Western Avenue bridge.
11.30 A.M., .	None.	V. slight.	.09	.0372	.0192	1188	Surface.	At Cottage Farm bridge.
11.30 A.M., .	None.	V. slight.	.08	.0388	.0176	1190	1 foot.	At Cottage Farm bridge.
11.30 A.M., .	None.	V. slight.	.06	.0384	.0140	1570	11 feet.	At Cottage Farm bridge.
11.50 A.M., .	None.	V. slight.	.07	.0384	.0196	1283	Surface.	At Muddy River outlet.
11.40 A.M., .	None.	V. slight.	.10	.0372	.0172	1320	2 feet.	At Muddy River outlet.
12.00 M., .	None.	V. slight.	.05	.0388	.0196	1312	Surface.	Just above Harvard bridge.
12.00 M., .	None.	V. slight.	.09	.0368	.0184	1315	1 foot.	Just above Harvard bridge.
12.00 M., .	None.	V. slight.	.04	.0324	.0144	1583	9 feet.	Just above Harvard bridge.

Low tide at 11.28 A.M.

TABLE NO. 6. — *Charles River, at About High Tide. — Oct. 10, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.			
4.30 P.M.,	V. slight.	V. slight.	.31	.0128	.0268	1.08	Surface.	At Watertown dam spillway.
4.15 P.M.,	Slight.	Cons.	–	.0108	.0296	3.70	Surface.	At Watertown race from Lewando's.
4.45 P.M.,	V. slight.	V. slight.	.30	.0124	.0288	1.15	Surface.	At Watertown gas works.
4.45 P.M.,	V. slight.	V. slight.	.28	.0108	.0260	7.60	1 foot.	At Watertown gas works.
5.30 P.M.,	None.	Slight.	.17	.0348	.0264	625.00	Surface.	At Watertown Arsenal.
5.30 P.M.,	None.	V. slight.	.18	.0300	.0256	682.50	1 foot.	At Watertown Arsenal.
5.30 P.M.,	None.	Slight.	.14	.0400	.0236	927.00	13 feet.	At Watertown Arsenal.
5.45 P.M.,	None.	V. slight.	.16	.0428	.0224	886.00	Surface.	At upper Western Avenue bridge.
5.45 P.M.,	None.	V. slight.	.15	.0508	.0244	928.00	1 foot.	At upper Western Avenue bridge.
5.50 P.M.,	None.	Slight.	.09	.0372	.0180	1130.00	14 feet.	At upper Western Avenue bridge.
6.00 P.M.,	None.	V. slight.	.05	.0388	.0164	1450.00	Surface.	At North Harvard Street bridge.
6.15 P.M.,	None.	None.	.05	.0376	.0148	1460.00	1 foot.	At North Harvard Street bridge.
6.15 P.M.,	None.	None.	.04	.0348	.0156	1535.00	17½ feet.	At North Harvard Street bridge.

High tide at 5.38 P.M.

TABLE No. 7. — *Charles River, Below Craigie Bridge. — Oct. 20, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.				
11.30 A.M.,	V. slight.	Slight.	.03	.0232	.0120	1715	68.7	Surface.	At new Charlestown bridge.
12.00 M.,	V. slight.	Slight.	.03	.0156	.0132	1760	70.0	37 feet.	At new Charlestown bridge.
12.30 P.M.,	V. slight.	V. slight.	.03	.0184	.0112	1735	69.8	Surface.	At new Charlestown bridge.
12.30 P.M.,	-	-	-	-	-	-	28.5	37 feet.	At new Charlestown bridge.
2.30 P.M.,	V. slight.	V. slight.	.03	.0188	.0116	1730	65.9	Surface.	At Warren bridge.
2.40 P.M.,	V. slight.	V. slight.	.03	.0184	.0116	1730	66.8	16 feet.	At Warren bridge.
3.30 P.M.,	V. slight.	Slight.	.03	.0200	.0144	1695	65.3	Surface.	At Warren bridge.
3.30 P.M.,	V. slight.	Slight.	.03	.0220	.0128	1700	64.7	Bottom.	At Warren bridge.
4.20 P.M.,	V. slight.	Slight.	.03	.0228	.0128	1660	64.7	Surface.	At Warren bridge.
4.30 P.M.,	V. slight.	Slight.	.03	.0264	.0152	1660	64.8	12 feet.	At Warren bridge.

High tide at 1.21 P.M.

TABLE No. 8.—*Charles River, Surface, Low Tide, Early Flood.—Oct. 23, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	APPEARANCE.			AMMONIA.		Chlorine.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.		
11.00 A.M.,	Decided.	Heavy, black.	–	.1310	.2520	–	At water front, Fairfield Street.
11.00 A.M.,	Slight.	None.	.07	.0460	.0264	1320	At Harvard bridge, twenty feet from south end.
11.00 A.M.,	V. slight.	Slight.	.04	.0244	.0144	1460	At Harvard bridge, half way to draw.
11.15 A.M.,	V. slight.	Slight.	.04	.0224	.0160	1540	At Harvard bridge draw.
11.15 A.M.,	V. slight.	Slight.	.04	.0248	.0160	1520	At Harvard bridge, twenty feet from north end.
11.45 A.M.,	Slight.	Cons.	.06	.0808	.0400	12	Stony Brook, under tide gate at Fenway.

Low tide at 9.54 A.M.

TABLE NO. 9. — *Charles River, at Harvard Bridge, Surface, Low Tide, Early Flood. — Oct. 28, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	APPEARANCE.			RESIDUE ON EVAPORATION.		AMMONIA.		Chlorine.	Source.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid.		
3.35 P.M.,	Decided.	Heavy.	.18	1849.40	380.00	.0860	.0750	887.50	Charles River, at Harvard bridge, 150 feet from south end.
3.40 P.M.,	Decided.	Heavy.	.21	1784.00	362.40	.1040	.1340	830.00	Charles River, at Harvard bridge, half way between south end and draw.
3.45 P.M.,	Slight.	Slight.	.15	3027.60	886.00	.0295	.0210	1310.00	Charles River, at Harvard bridge draw.
3.50 P.M.,	V. slight.	V. slight.	.10	3156.40	956.00	.0240	.0172	1350.00	Charles River, at Harvard bridge, half way between north end and draw.
4.05 P.M.,	Decided.	Cons.	.30*	1460.40	286.00	.1140	.0840	703.00	Stony Brook, outlet.
4.15 P.M.,	Decided.	Cons.	.28*	1651.40	278.00	.0820	.0820	777.50	Muddy River, outlet.

Low tide at 3.01 P.M.

* Turbid.

TABLE NO. 10. — *Charles River, at Craigie Bridge, Samples at Various Depths, at Low Tide, Late Ebb and Early Flood. — Sept. 15, 1902.*

[Parts per 100,000.]

Time of Collection.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Bacteria per c. c.	Depth.
2.10 P.M.,	.0264	.0132	1592.0	–	Surface.
2.15 P.M.,	.0288	.0176	1592.0	–	6 inches.
2.20 P.M.,	.0240	.0168	1592.0	1,058	1 foot.
2.20 P.M.,	.0264	.0142	1590.0	–	2 feet.
2.25 P.M.,	.0276	.0132	1590.0	530	3 feet.
2.30 P.M.,	.0288	.0132	1585.0	–	5 feet.
2.30 P.M.,	.0264	.0144	1642.0	1,440	7 feet.
2.40 P.M.,	.0284	.0136	1615.0	–	9 feet.
2.45 P.M.,	.0264	.0132	1622.0	290	11 feet.
2.50 P.M.,	.0260	.0120	1631.0	–	13 feet.
2.50 P.M.,	.0260	.0136	1631.0	242	15 feet.
3.00 P.M.,	.0264	.0152	1635.0	–	17 feet.
3.00 P.M.,	.0620	.0240	1635.0	–	19 feet.
3.15 P.M.,	.0244	.0148	1638.0	–	21 feet.
3.20 P.M.,	.0268	.0120	1642.0	272	23 feet.
3.25 P.M.,	.0244	.0164	1632.0	12,300	Surface.
3.30 P.M.,	.0260	.0140	1638.0	–	6 inches.
3.40 P.M.,	.0272	.0140	1637.0	–	1 foot.
3.40 P.M.,	.0248	.0156	1632.0	–	2 feet.
3.45 P.M.,	.0320	.0124	1631.0	–	3 feet.
3.45 P.M.,	.0296	.0188	1614.5	–	5 feet.
3.50 P.M.,	.0256	.0124	1617.0	–	7 feet.
3.50 P.M.,	.0292	.0084	1615.5	–	9 feet.
4.00 P.M.,	.0272	.0132	1621.0	–	11 feet.
4.00 P.M.,	.0252	.0140	1628.0	–	13 feet.
4.10 P.M.,	.0316	.0140	1637.0	–	16 feet.
4.15 P.M.,	.0268	.0120	1639.0	–	19 feet.

Low tide at 3.28 P.M.

TABLE No. 11. — *Charles River, at West Boston ("Cambridge") Bridge, at Various Depths, beginning at Low Tide, continuing throughout Flood and Ebb. — Sept. 19, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	Color.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Depth.
6.55 A.M.,	.04	.0308	.0168	1600	Surface.
7.00 A.M.,	.04	.0316	.0188	1610	1 foot.
7.45 A.M.,	.06	.0344	.0184	1640	12 feet.
8.25 A.M.,	.05	.0380	.0188	1660	Surface.
8.25 A.M.,	.05	.0300	.0152	1670	1 foot.
8.40 A.M.,	.03	.0288	.0168	1670	12 feet.
9.00 A.M.,	.03	.0284	.0220	1680	Surface.
9.00 A.M.,	.03	.0292	.0152	1690	1 foot.
9.10 A.M.,	.03	.0268	.0156	1695	12 feet.
10.00 A.M.,	.03	.0212	.0156	1715	Surface.
10.00 A.M.,	.03	.0224	.0156	1720	1 foot.
10.05 A.M.,	.03	.0380	.0152	1730	12 feet.
10.40 A.M.,	.03	.0212	.0176	1725	Surface.
11.00 A.M.,	.03	.0220	.0140	1730	1 foot.
11.00 A.M.,	.03	.0220	.0144	1730	12 feet.
12.00 M.,	.03	.0228	.0152	1725	Surface.
12.00 M.,	.03	.0200	.0164	1730	1 foot.
12.35 P.M.,	.03	.0204	.0144	1730	12 feet.
1.00 P.M.,	.03	.0236	.0232	1720	Surface.
1.00 P.M.,	.03	.0232	.0188	1735	1 foot.
1.00 P.M.,	.03	.0232	.0168	1740	12 feet.
2.00 P.M.,	.03	.0260	.0188	1710	Surface.
2.00 P.M.,	.03	.0256	.0156	1710	1 foot.
2.10 P.M.,	.03	.0232	.0160	1725	12 feet.
3.00 P.M.,	.03	.0220	.0164	1670	Surface.
3.00 P.M.,	.03	.0260	.0160	1675	1 foot.
3.10 P.M.,	.03	.0248	.0160	1695	12 feet.
4.00 P.M.,	.03	.0312	.0192	1600	Surface.
4.00 P.M.,	.03	.0304	.0164	1605	1 foot.
4.05 P.M.,	.03	.0232	.0164	1675	12 feet.
5.00 P.M.,	.05	.0328	.0288	1585	Surface.
5.00 P.M.,	.05	.0320	.0204	1595	1 foot.
5.00 P.M.,	.05	.0304	.0196	1635	12 feet.
5.45 P.M.,	.04	.0352	.0356	1580	Surface.
5.45 P.M.,	.05	.0340	.0184	1580	1 foot.
6.20 P.M.,	.04	.0328	.0200	1595	10 feet.
6.30 P.M.,	.03	.0324	0180	1590	Surface.
6.30 P.M.,	.04	.0324	.0192	1590	1 foot.
6.30 P.M.,	.04	.0296	.0180	1590	10 feet.

Low tide at 6.02 A.M.; high tide at 12.11 P.M.; low tide at 6.27 P.M.

TABLE NO. 12.— *Charles River, at Harvard Bridge, at Various Depths, beginning at Low Tide, continuing throughout Flood and to One-quarter Ebb.— Sept. 6, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	AMMONIA. Free.	AMMONIA. Albuminoid.	Chlorine.	Depth.
8.15 A.M.,	.0324	.0244	1387	Surface.
8.15 A.M.,	.0328	.0252	1373	6 inches.
8.30 A.M.,	.0324	.0244	1413	1½ feet.
8.30 A.M.,	.0312	.0208	1431	3 feet.
8.30 A.M.,	.0324	.0200	1510	6 feet.
8.40 A.M.,	.0312	.0220	1528	9 feet.
9.00 A.M.,	.0308	.0204	1545	12 feet.
9.00 A.M.,	.0336	.0272	1495	Surface.
9.10 A.M.,	.0312	.0252	1520	6 inches.
9.10 A.M.,	.0320	.0184	1585	1½ feet.
9.20 A.M.,	.0300	.0196	1590	3 feet.
9.20 A.M.,	.0316	.0208	1580	6 feet.
9.30 A.M.,	.0424	.0188	1500	Surface.
9.40 A.M.,	.0352	.0224	1510	6 inches.
1.45 P.M.,	.0272	.0180	1613	Surface.
1.47 P.M.,	.0328	.0168	1622	6 inches.
1.50 P.M.,	.0284	.0200	1638	1½ feet.
1.52 P.M.,	.0436	.0204	1615	3 feet.
1.55 P.M.,	.0324	.0180	1630	6 feet.
1.57 P.M.,	.0308	.0204	1620	9 feet.
2.03 P.M.,	.0296	.0200	1628	12 feet.
2.07 P.M.,	.0288	.0216	1645	15 feet.
2.11 P.M.,	.0288	.0184	1640	18 feet.
2.15 P.M.,	.0276	.0180	1648	21 feet.
2.32 P.M.,	.0352	.0184	1625	Surface.
2.35 P.M.,	.0304	.0184	1625	6 inches.
2.38 P.M.,	.0320	.0188	1625	1½ feet.
2.42 P.M.,	.0292	.0180	1623	3 feet.
2.45 P.M.,	.0284	.0160	1620	6 feet.
2.51 P.M.,	.0304	.0160	1635	9 feet.
2.54 P.M.,	.0280	.0208	1640	12 feet.
2.58 P.M.,	.0280	.0172	1635	15 feet.
3.08 P.M.,	.0328	.0180	1615	Surface.
3.11 P.M.,	.0332	.0172	1612	6 feet.
3.15 P.M.,	.0296	.0184	1613	1½ feet.
3.18 P.M.,	.0312	.0196	1615	3 feet.
3.22 P.M.,	.0280	.0176	1627	6 feet.
3.27 P.M.,	.0296	.0176	1635	8 feet.

Low tide at 8.01 A.M.; high tide at 2.12 P.M.

TABLE No. 13. — *Charles River, One Mile above Harvard Bridge, at Various Depths, beginning at Low Tide, continuing throughout Flood and Early Ebb. — Sept. 8, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	AMMONIA. Free.	AMMONIA. Albuminoid.	Chlorine.	Depth.
11.10 A.M.,	.0424	.0264	1398	Surface.
11.10 A.M.,	.0392	.0244	1395	6 inches.
11.25 A.M.,	.0368	.0204	1550	1½ feet.
11.25 A.M.,	.0352	.0188	1545	3 feet.
11.35 A.M.,	.0328	.0196	1585	6 feet.
11.40 A.M.,	.0316	.0180	1598	9 feet.
11.45 A.M.,	.0332	.0204	1624	12 feet.
12.00 M.,	.0356	.0220	1420	Surface.
12.05 P.M.,	.0384	.0204	1455	6 inches.
12.10 P.M.,	.0436	.0200	1498	1½ feet.
12.15 P.M.,	.0368	.0180	1510	3 feet.
12.15 P.M.,	.0364	.0204	1610	6 feet.
12.20 P.M.,	.0340	.0200	1632	9 feet.
12.30 P.M.,	.0328	.0156	1642	12 feet.
3.45 P.M.,	.0348	.0180	1590	Surface.
3.45 P.M.,	.0340	.0180	1592	6 inches.
3.45 P.M.,	.0348	.0156	1603	1½ feet.
3.50 P.M.,	.0308	.0180	1610	3 feet.
3.50 P.M.,	.0300	.0168	1634	6 feet.
3.50 P.M.,	.0304	.0164	1640	9 feet.
4.00 P.M.,	.0300	.0164	1635	12 feet.
4.00 P.M.,	.0340	.0176	1650	15 feet.
4.00 P.M.,	.0316	.0188	1650	18 feet.
4.15 P.M.,	.0344	.0184	1590	Surface.
4.15 P.M.,	.0316	.0188	1584	6 inches.
4.15 P.M.,	.0328	.0184	1592	1½ feet.
4.25 P.M.,	.0296	.0164	1620	3 feet.
4.25 P.M.,	.0284	.0176	1638	6 feet.
4.30 P.M.,	.0340	.0188	1638	9 feet.
4.30 P.M.,	.0336	.0176	1644	12 feet.
4.30 P.M.,	.0296	.0164	1635	15 feet.
4.35 P.M.,	.0312	.0176	1650	18 feet.

Low tide at 9.35 A.M.; high tide at 3.46 P.M.

As the sea water enters the basin above the numerous pile bridges near the northern railroad station, it comes in well mixed and almost as a solid wall, so to speak, apparently pushing the fresh water back, or mixing with it even as far up the basin as Lower Western Avenue, little difference between surface and bottom samples, as far as chlorine is concerned, being noted in the lower portion of the basin, although the proportion of fresh water mixed with the salt water increases regularly as the tide advances. In the upper portion of the river, as at Upper Western Avenue, however, there is considerable difference in the chlorine contents of the upper and lower layers of water. As the tide turns and the water in the basin lowers, the presence of fresh water over a larger section of the basin is noticeable, this fresh water being largely held at or near the surface, as shown by many examinations of samples taken at different locations and from the surface downward.

This, of course, results from the difference in specific gravity of fresh and salt water. There is, however, a constant tendency for the two waters to become mixed, owing to the swiftness of the current, the many abrupt turns of the river, the difference in depth of the river at different places, and the many bridges with pile supports, especially in its lower course.

Pure sea water of the north Atlantic coast contains about 1,825 parts of chlorine per 100,000 parts. The highest chlorine found in any sample collected in the lower portion of the basin at high tide was 1,740 parts, showing that enough fresh water was mixed with this sample to lower the chlorine 85 parts; that is, about 4.6 per cent of fresh water was mixed with the sea water at West Boston bridge at high tide on September 19, at a depth of from 15 to 21 feet, and from this point up the river the proportion of fresh water increased steadily, until at Upper Western Avenue bridge the mixture was about half and half.

Some of these chlorine results are shown in the following tables, but many other determinations have been made, and are given in tables upon pages 223–234.

Chlorine Observations at Different Depths in Charles River Basin, at High Water and at Low Water, at Six Stations, from Upper Western Avenue Bridge, Brighton, to Warren Bridge, Charlestown, Mass., 1902.

[Parts per 100,000.]

Depth of Water at which Sample was taken (Feet below Surface).	Upper Western Avenue Bridge. High Water, Nov. 1, 12.14 P.M. Time of Collection.	Chlorine.	Upper Western Avenue Bridge. Low Water, Nov. 12, 2.48 P.M. Time of Collection.	Chlorine.	Lower Western Avenue Bridge. High Water, Oct. 31, 11.28 A.M. Time of Collection.	Chlorine.	Lower Western Avenue Bridge. Low Water, Oct. 31, 5.44 P.M. Time of Collection.	Chlorine.
	A.M.		P.M.		A.M.		P.M.	
Surface,	11.35	890	1.45	324	11.00	1490	4.50	805
½,	11.35	890	1.55	329	11.09	1490	4.50	800
1,	11.45	910	2.00	331	11.00	1490	5.00	790
1½,	–	–	–	–	–	–	–	–
2,	11.45	915	2.05	333	11.10	1500	5.00	785
3,	11.50	950	2.05	341	11.15	1495	5.10	775
4,	–	–	2.10	342	–	–	–	–
5,	11.50	990	2.15	344	11.20	1505	5.15	775
6,	–	–	–	–	–	–	–	–
7,	M. 12.00	1040	–	–	11.20	1500	–	–
8,	–	–	–	–	–	–	5.20	765
9,	12.00	1070	–	–	11.30	1495	–	–
10,	–	–	–	–	–	–	–	–
11,	–	–	–	–	–	–	–	–
12,	P.M. 12.10	1090	–	–	11.30	1500	–	–
13,	–	–	–	–	–	–	–	–

Depth of Water at which Sample was taken (Feet below Surface).	Harvard Bridge. High Water, Sept. 6, 2.27 P.M. Time of Collection.	Chlorine.	Harvard Bridge. Low Water, Sept. 6, 8.16 A.M. Time of Collection.	Chlorine.	West Boston Bridge. High Water, Nov. 13, 9.04 A.M. Time of Collection.	Chlorine.	West Boston Bridge. Low Water, Sept. 19, 6.37 P.M. Time of Collection.	Chlorine.
	P.M.		A.M.		A.M.		P.M.	
Surface,	2.32	1625	8.15	1387	8.40	1670	5.45	1585
½,	2.35	1625	8.15	1373	8.40	1670	5.45	1585
1,	–	–	–	–	8.55	1670	5.45	1585
1½,	2.38	1625	8.30	1413	–	–	–	–
2,	–	–	–	–	8.55	1670	5.55	1590
3,	2.42	1623	8.30	1431	9.00	1675	6.00	1595
4,	–	–	–	–	9.00	1675	–	–
5,	–	–	–	–	9.05	1675	6.00	1595
6,	2.45	1620	8.30	1510	–	–	–	–
7,	–	–	–	–	–	–	6.05	1590
8,	–	–	–	–	–	–	–	–
9,	2.51	1635	8.40	1528	9.10	1675	6.10	1595
10,	–	–	–	–	–	–	6.15	1595
11,	–	–	–	–	–	–	–	–
12,	2.54	1640	9.00	1545	–	–	–	–
13,	–	–	–	–	–	–	–	–

Depth of Water at which Sample was taken (Feet below Surface).	Craigie Bridge. High Water, Nov. 7, 4.15 P.M. Time of Collection.	Chlorine.	Craigie Bridge. Low Water, Sept. 15, 3.38 P.M. Time of Collection.	Chlorine.	Warren Bridge. High Water, Nov. 7, 4.05 P.M. Time of Collection.	Chlorine.	Warren Bridge. Low Water, Dec. 18, 7.27 A.M. Time of Collection.	Chlorine.
	P.M.		P.M.		P.M.			
Surface,	4.00	1650	2.10	1592	3.00	1690	8.00	1490
½,	4.05	1650	2.15	1592	3.05	1700	–	–
1,	4.10	1650	2.20	1592	3.10	1695	8 03	1500
1½,	–	–	–	–	–	–	–	–
2,	–	–	2.20	1590	3.15	1695	–	–
3,	4.15	1650	2.25	1590	3.20	1700	8.06	1505
4,	–	–	–	–	3.20	1695	–	–
5,	4.15	1660	2.30	1585	3.25	1710	8.10	1510
6,	–	–	–	–	–	–	–	–
7,	–	–	2.30	1642	–	–	–	–
8,	–	–	–	–	3.35	1705	8.14	1510
9,	4.20	1680	2.40	1615	–	–	–	–
10,	–	–	–	–	–	–	–	–
11,	–	–	2.45	1622	–	–	–	–
12,	–	–	–	–	3.35	1705	8.18	1510
13,	–	–	2.50	1631	–	–	–	–

14, . .	-	-	-	-	-	-	-	-	-	-	-	-	9.15	1680	-	-	4.30	1675	-	-	3.40	1710	-	-
15, . .	-	-	-	-	11.40	1500	-	-	2.58	1635	-	-	-	-	-	-	-	-	2.50	1631	-	-	-	-
15½, . .	12.15	1140	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17, . .	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.00	1635	-	-	-	-
18, . .	-	-	-	-	11.45	1490	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19, . .	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.00	1635	-	-	-	-
20, . .	-	-	-	-	-	-	-	-	-	-	-	-	9.15	1680	-	-	-	-	-	-	-	-	-	-
21, . .	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.15	1638	-	-	-	-
23, . .	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.20	1642	-	-	-	-
24, . .	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.30	1685	-	-	-	-	-	-
34, . .	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.35	1695	-	-	-	-	-	-

Amounts of Fresh Water entering Charles River Basin, at Watertown Dam, on Days immediately Prior to Collection of Above Samples, as reported by J. R. Freeman, C.E.

[Million gallons per 24 hours.]

	Oct. 29	70.2	Nov. 9	13.2	Oct. 28	71.6	-	-	Sept. 3	19	-	-	Nov. 10	85.7	Sept. 16	19	Nov. 4	99.4	Sept. 12	19	-	-	-	-
	30	87.4	10	85.7	29	70.2	-	-	4	19	-	-	11	104.4	17	19	5	98.6	13	11	-	-	-	-
	31	95.7	11	104.4	30	87.4	-	-	5	19	-	-	12	97.6	18	19	6	99.7	14	8	-	-	-	-
	Nov. 1	72.6	12	97.6	31	95.7	-	-	6	8	-	-	13	99.4	19	19	7	99.2	15	19	-	-	-	-

Chlorine Observations in Charles River Basin, Between Watertown Dam and West Boston Bridge, 1902.

[Parts per 100,000.]

Location.	September 4.				October 6.				October 10.			
	Time of Collection.	Number of Hours after High Water.	Depth of Sample (Feet).	Chlorine.	Time of Collection.	Number of Hours before or after High Water.	Depth of Sample (Feet).	Chlorine.	Time of Collection.	Number of Hours before or after High Water.	Depth of Sample (Feet).	Chlorine.
Just below Watertown dam,	P.M. -	-	-	-	P.M. 1.00	2 before.	Surface.	.90	P.M. -	-	-	-
At Watertown gas works,	-	-	-	-	-	-	-	-	4.45	1¼ before.	Surface.	1.15
	-	-	-	-	-	-	-	-	4.45	-	1	7.60
One-quarter mile below Watertown dam,	-	-	-	-	12.45	2¼ before.	Surface.	11.50	-	-	-	-
Opposite Watertown Arsenal,	-	-	-	-	2.00	¾ before.	Surface.	445.00	5.30	½ before.	Surface.	625.00
	-	-	-	-	-	-	-	-	5.30	-	1	682.50
	-	-	-	-	-	-	-	-	5.30	-	13	927.00
Opposite Brighton Abattoir,	-	-	-	-	2.15	½ before.	Surface.	1125.00	-	-	-	-
Upper Western Avenue bridge,	1.45	¾	Surface.	1250.00	-	-	-	-	5.45	¼ before.	Surface.	886.00
	1.45	-	7	1425.00	-	-	-	-	5.45	-	1	928.00
	-	-	-	-	-	-	-	-	5.50	-	14	1130.00
Opposite lower end of Cambridge cemetery,	-	-	-	-	2.30	¼ before.	Surface.	1248.00	-	-	-	-

North Harvard Street bridge,	2.35	1½	Surface.	1540.00	2.40	High water.	Surface.	1498.00	6.00	High water.	Surface.	1450.00
	2.35	-	11	1530.00	-	-	-	-	6.15	¼ after.	1	1460.00
	-	-	-	-	-	-	-	-	6.15	-	17½	1535.00
Lower Western Avenue bridge,	-	-	-	-	2.45	High water.	Surface.	1540.00	-	-	-	-
Cottage Farm bridge,	3.15	3¼	Surface.	1570.00	3.00	¼ after.	Surface.	1540.00	-	-	-	-
	3.15	-	6	1560.00	-	-	-	-	-	-	-	-
Harvard bridge, middle,	4.15	4¼	Surface.	1600.00	-	-	-	-	-	-	-	-
Harvard bridge, middle,	4.15	-	6	1620.00	-	-	-	-	-	-	-	-
Harvard bridge, north end,	-	-	-	-	3.00	¼ after.	Surface.	1555.00	-	-	-	-
Harvard bridge, south end,	-	-	-	-	3.15	½ after.	Surface.	1575.00	-	-	-	-
Between Harvard bridge and West Boston bridge,	-	-	-	-	3.20	¾ after.	Surface.	1615.00	-	-	-	-
West Boston bridge,	-	-	-	-	3.30	1 after.	Surface.	1625.00	-	-	-	-
Predicted time of high water at Charlestown Navy Yard,	12.41 P.M.				2.24 P.M.				5.38 P.M.			

Amount of Fresh Water entering Charles River Basin at Watertown Dam, as reported by J. R. Freeman, C.E.

[Million gallons per 24 hours.]

	Sept. 1.	Sept. 2.	Sept. 3.	Sept. 4.	Oct. 3.	Oct. 4.	Oct. 5.	Oct. 6.	Oct. 7.	Oct. 8.	Oct. 9.	Oct. 10.
	3	19	19	19	44.6	51.6	15.2	44.5	53.3	53.8	55.4	56.3

Quality of the Fresh Water.

The fresh water of the Charles River entering the basin over Watertown dam in the summer season, as represented in this study by the month of September, — omitting for the present all other fresh water from sewer overflows, drains, etc., — contains a greater amount of organic matter than the sea water which enters the basin from the harbor. The amount of organic matter present in the fresh water, as shown by the albuminoid ammonia determinations, is about twice as great as that in the harbor water, and the free ammonia is nearly twice as great; that is, judging from many analyses made, an average analysis of this water in dry summer weather would show the free ammonia to be about .0350 parts and the albuminoid ammonia about .0370 parts per 100,000 (see tables Nos. 14–24).

As far as the physical characteristics of the water are concerned, most of the samples collected just above or at Watertown dam have had very slight or no turbidity, a varying amount of sediment, a color considerably lower than that of the former Boston supply, and at times a musty odor. The number of bacteria present has varied from 1,000 to 13,500 per c. c. Upon the dates on which the samples used to make the averages in the preceding paragraph were collected, the water in the river was low enough so that only during a portion of the days was water passing over Watertown dam, and then during most of the time in a thin stream only. That is, only about enough water for use at the factory, dye house, etc., was flowing in the river, and that was passing into the raceway (see table of flow of Charles River at Watertown dam, on page 237). Samples collected just below the dam upon some of these days were of practically the same character. All the water contained considerable dissolved oxygen (see tables Nos. 14–24).

During September and October many samples were collected, covering the river from Newton Upper Falls to Watertown dam, and the results of the examinations and analyses are given in tables Nos. 14–24. Studying these analyses in detail, we see that the water in the river upon September 25 from Newton Lower Falls as far down as Waltham dam was of as good quality as the best sea water filling the basin at high tide; low in organic matter, as shown by the determinations of albuminoid ammonia and oxygen consumed; low in color; odorless; and containing, from the surface to the bottom of the river, from 60 to 70 per cent. of the volume of oxygen required for saturation. From this point down samples were collected upon October 3 (see Table No. 20); and, with the exception of the one collected near the right end of Elm Street bridge, in Waltham, where gas works wastes enter, the increase in organic matter was not rapid. The final sample, taken at Farwell Street bridge, although containing nearly twice as much free ammonia as the sample taken just below Newton Lower Falls, did not contain as much organic matter as this upper sample, but it did contain rather more than the average amount in the intervening samples. It contained 71 per cent. of dissolved oxygen. The amount of dissolved oxygen in the river water from Newton Lower Falls to a point below the bleachery at Waltham, as shown by these examinations, was large, and about the same at all locations and depths.

Other samples of the river water above Watertown dam were collected at different locations upon September 5, 11, 17 and 22, and the analyses are given on tables following. The increase of the organic matter in the river water between Waltham and Watertown dam is noticeable, as are also the increased color and turbidity. Some of these

samples were collected, however, in places where the river was noticeably dirty, and hence exaggerate the real amount of organic matter present in the river water as a whole. It was noticeable that under the worst conditions found there was considerable free oxygen in the river water at all depths.

Samples of the upland river water were again collected on October 15 and 16 from points above Riverside to Watertown dam, and the analyses showed very little variation in organic contents until a point below Bemis was reached (see tables Nos. 21 and 22). The organic matter present in the water above Bemis upon these dates was certainly not great enough to bar the use of this water for a public water supply. The known entrance of drainage and the bacterial contents would, however. The number of bacteria present upon these dates, as shown upon later pages, varied at different points and depths from a few hundred to 22,000 per c. c.*

Beginning at 7.45 A.M. and ending at 4.45 P.M. upon October 17 a series of samples of the water flowing over Watertown dam was taken. These analyses are given in tables following, and show the water upon that date to be fairly clear, low in color, practically odorless, only the odor of vegetable matter being noted; containing a comparatively small amount of organic matter, with bacteria varying from 1,900 to 9,300 per c. c.; and containing from 60 to 74 per cent. of the volume of dissolved oxygen necessary for saturation. Rains had occurred since the collection of a similar series upon September 22. The tables of analyses follow.

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* A coffer dam was constructed in the Charles River near Norumbega Park by the Metropolitan Water and Sewerage Board, beginning August 15 and continuing until September 20. About October 1 water was pumped from the inside of the dam, and the excavation of mud and gravel was in progress until October 15. This work probably had some effect upon the quality of the water flowing in the river during at least a part of this period.

TABLE NO. 14. — *Charles River, Above Watertown Dam. — Sept. 5, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Depth.	Source.
							Albuminoid.								
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.			
2.30 P.M., . .	Slight.	Cons.	.48	26.00	8.00	.0040	.0520	.0372	.0148	0.88	.0150	.0013	0.74	-	Above Bemis dam, mid-stream.
2.05 P.M., . .	Slight.	Cons.	.50	43.00	9.00	.0040	.0536	.0384	.0152	0.88	.0160	.0013	0.68	-	Above Bemis dam, left bank.
3.40 P.M., . .	Slight.	Cons., green.	.44	15.00	6.00	.0110	.0870	.0345	.0525	0.87	.0080	.0007	1.14	-	Above Watertown dam, mid-stream.
3.30 P.M., . .	Decided.	Cons.	.44	11.00	4.00	.0120	.0448	.0344	.0104	0.87	.0100	.0010	0.58	-	Above Watertown dam, left bank.

TABLE NO. 15. — *Charles River, Near Watertown Dam. — Sept. 9, 1902.*

Time of Collection.	Turbidity.	Sediment.	Color.	Residue: Total.	Residue: Loss on Ignition.	Ammonia: Free.	Albuminoid: Total.	Albuminoid: Dissolved.	Albuminoid: Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Depth.	Source.
1.15 P.M., . .	Decided.	Cons.	.36*	27.50	5.30	.0256	.0464	.0276	.0188	1.01	.0360	.0052	0.55	Surface.	Above dam, at Waltham Street.
1.00 P.M., . .	Decided.	Cons.	.40*	14.30	3.30	.0256	.0420	.0308	.0112	1.05	.0280	.0048	0.68	Surface.	Above dam, at Howard Street.
12.10 P.M., . .	Decided.	Cons.	.42*	14.30	4.30	.0320	.0476	.0296	.0180	1.08	.0250	.0052	0.78	Surface.	Above dam, opposite starch works.
11.45 A.M., . .	Decided.	Cons.	.40*	13.00	3.60	.0148	.0368	.0288	.0080	1.09	.0070	.0064	0.60	6 inches.	Below dam, at Galen Street bridge.

* Poor color.

TABLE No. 16. — *Charles River, Near Watertown Dam. — Sept. 11, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
							Albuminoid.									
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.				
2.20 P.M., .	Slight.	Cons.	.43*	33.80	5.50	.0004	.0380	.0292	.0088	1.02	.0080	.0018	.88	–	Surface.	Above dam, at Waltham Street.
2.20 P.M., .	Slight.	Cons.	.46*	32.80	6.30	.0008	.0400	.0284	.0116	0.96	.0080	.0024	.86	–	10 inches.	Above dam, at Waltham Street.
2.45 P.M., .	Slight.	Cons.	.54	11.30	3.50	.0008	.0336	.0308	.0028	1.05	.0060	.0018	.82	–	Surface.	Above dam, at Howard Street.
2.45 P.M., .	Decided.	Cons.	.45	11.40	3.60	.0040	.0388	.0312	.0076	0.96	.0070	.0021	.80	–	3 feet.	Above dam, at Howard Street.
1.20 P.M., .	Decided.	Cons.	.30	12.50	3.50	.0196	.0284	.0212	.0072	1.02	.0500	.0052	.48	–	Surface.	Below dam, at Galen Street bridge, south end.
1.10 P.M., .	V. slight.	Cons.	.46	10.50	3.00	.0024	.0344	.0308	.0036	1.00	.0050	.0019	.80	–	Surface.	Below dam, at Galen Street bridge, north end.

TABLE No. 17. — *Charles River, at Watertown. — Sept. 17, 1902.*

2.30 P.M., .	Decided.	Cons.	.36*	10.00	2.80	.0116	.0448	.0348	.0100	0.98	.0200	.0016	.54	49.8	Surface.	Above dam, at Waltham Street.
3.05 P.M., .	Decided.	Slight.	.35*	11.20	2.90	.0112	.0420	.0376	.0044	0.96	.0200	.0016	.56	49.7	6 inches.	Above dam, at Waltham Street.
3.25 P.M., .	Decided.	Cons.	.35*	10.20	3.00	.0072	.0384	.0340	.0044	0.92	.0170	.0014	.72	47.0	Surface.	Above dam, at Howard Street.
3.30 P.M., .	–	–	–	–	–	–	–	–	–	–	–	–	–	48.4	Surface.	Above dam, at Howard Street.
3.50 P.M., .	–	–	–	–	–	–	–	–	–	–	–	–	–	68.0	Surface.	At starch works, California Street.

* Turbid.

TABLE No. 18. — *Charles River, at Watertown, Surface.* — *Sept. 22, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.					Nitrogen as					
							Albuminoid.									
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Bacteria per c. c.	Source.
7.00 A.M., .	V. slight.	Slight.	.41	15.60	4.40	.0530	.0420	.0240	.0180	1.08	.019	.0012	0.83	6.7	362	At Watertown dam.
8.40 A.M., .	V. slight.	Slight.	.23	17.30	4.90	.0260	.0180	.0100	.0080	1.10	.121	.0050	0.36	-	-	Howard's Pond, near Charles River.
11.00 A.M., .	V. slight.	Heavy.	.46	14.80	4.40	.0570	.0300	.0276	.0024	1.38	.019	.0008	0.60	-	-	Below Watertown dam, tail race below Galen Street bridge.
12.30 P.M., .	None.	V slight.	.41	13.60	4.40	.0652	.0240	.0240	.0000	0.83	.003	.0008	0.69	22.2	9,700	At Watertown dam.
1.30 P.M., .	None.	V. slight.	.41	13.70	3.20	.0692	.0260	.0260	.0000	0.75	.003	.0008	0.56	22.1	2,300	At Watertown dam.
2.00 P M., .	V. slight.	Decided.	.42	23.20	5.70	.0505	.0320	.0248	.0072	1.64	.029	.0010	0.52	-	-	Below Watertown dam, tail race at Galen Street bridge.
2.15 P.M., .	Slight.	Heavy.	.44	34.60	10.60	.0180	.0320	.0285	.0035	2.28	.055	.0020	1.68	-	-	Below Watertown dam, tail race at Galen Street bridge.
2.30 P.M., .	None.	V. slight.	.39	13.50	4.80	.0688	.0256	.0240	.0016	0.55	.005	.0014	0.50	27.7	1,066	At Watertown dam
3.30 P.M., .	None.	V. slight.	.39	15.20	5.10	.0668	.0308	.0252	.0056	0.78	.009	.0024	0.47	32.1	4,300	At Watertown dam.
4.30 P.M., .	None.	V. slight.	.39	13.80	4.90	.0578	.0264	.0256	.0008	0.80	.021	.0035	0.49	26.5	13,500	At Watertown dam.

7.00 A.M. — No water flowing over dam.
12.30 P.M. — Water beginning to flow over dam.
2.30 P.M. — Strong flow over dam.

TABLE NO. 19. — *Charles River, Above Waltham. — Sept. 25, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
							Albuminoid.									
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.				
11.45 A.M., .	Decided.	Cons.	.38	8.70	3.30	.0196	.0356	.0240	.0116	.68	.0080	.0002	.50	70.2	Surface.	Below Newton Lower Falls.
12.00 M., .	Slight.	Slight.	.35	7.80	2.50	.0204	.0316	.0228	.0088	.70	.0090	.0002	.49	67.8	14 inches.	Below Newton Lower Falls.
12.55 P.M., .	V. slight.	V. slight.	.37	7.20	2.20	.0144	.0240	.0220	.0020	.69	.0100	.0008	.41	64.6	Surface.	Below Auburndale bridge.
1.00 P.M., .	V. slight.	V. slight.	.33	12.80	7.60	.0156	.0280	.0244	.0036	.70	.0060	.0003	.46	56.8	3 feet.	Below Auburndale bridge.
1.45 P.M., .	-	-	-	-	-	-	-	-	-	-	-	-	-	61.4	Surface.	One mile below Weston bridge.
1.45 P.M., .	V. slight.	Slight.	.33	7.00	2.30	.0074	.0188	-	-	.72	.0060	.0004	.40	59.7	4½ feet.	One mile below Weston bridge.
2.15 P.M., .	V. slight.	V. slight	.29	8.50	2.60	.0136	.0225	.0212	.0013	.68	.0080	.0003	.40	63.7	Surface.	Just below Waltham pumping station.
2.15 P.M., .	V. slight.	V. slight.	.29	7.60	2.70	.0128	.0228	.0196	.0032	.68	.0080	.0005	.35	62.8	12 feet.	Just below Waltham pumping station.
3.10 P.M., .	Slight.	Slight.	.29	8.00	2.80	.0132	.0304	.0256	.0048	.70	.0090	.0005	.37	63.7	Surface.	At Waltham dam.
3.10 P.M., .	Slight.	Slight.	.29	6.80	2.20	.0136	.0216	.0192	.0024	.68	.0070	.0003	.38	65.8	8 feet.	At Waltham dam.

TABLE No. 20. — *Charles River, at Waltham. — Oct. 3, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	APPEARANCE.			RESIDUE ON EVAPORATION.		AMMONIA.				Chlorine.	NITROGEN AS		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	ALBUMINOID. Total.	ALBUMINOID. Dissolved.	ALBUMINOID. Suspended.		Nitrates.	Nitrites.				
11.40 A.M., .	V. slight.	V. slight.	.32	7.60	3.00	.0156	.0240	.0212	.0028	0.74	.0080	.0006	.39	72.8	Surface.	Elm Street bridge, below Boston Manufacturing Company, left end.
11.40 A.M., .	V. slight.	V. slight.	.31	8.80	2.50	.0168	.0248	.0216	.0032	0.74	.0090	.0005	.39	65.3	Surface.	Elm Street bridge, below Boston Manufacturing Company, centre.
12.00 M., .	V. slight.	Slight.	.30	8.50	2.50	.1312	.0260	.0248	.0012	0.82	.0100	.0002	.52	58.7	Surface.	Elm Street bridge, below Boston Manufacturing Company, right end.
12.30 P.M., .	V. slight.	Slight.	.01	33.00	10.50	.0336	.0104	.0072	.0032	5.10	.8000	.0010	.14	-	Surface.	Thirty-inch sewer entering river at left end of Elm Street bridge.
12.45 P.M., .	Decided.	Cons.	.33	9.30	2.50	.0332	.0304	.0252	.0052	1.00	.0220	.0007	.63	71.1	Surface.	Farwell Street bridge, below bleachery.
12.50 P.M., .	V. slight.	Cons.	.34	8.00	2.80	.0328	.0252	.0236	.0016	0.88	.0200	.0008	.50	71.2	3 feet.	Farwell Street bridge, below bleachery.
1.35 P.M., .	Decided.	Cons.	.40	11.70	3.00	.0256	.0384	.0312	.0072	0.90	.0200	.0012	.80	54.9	Surface.	Race of Ætna Woolen Mills, Bemis.

TABLE No. 21. — *Charles River, Above Waltham Dam. — Oct. 15, 1902.*

TIME OF COLLECTION.	Turbidity.	Sediment.	Color.	Residue Total.	Loss on Ignition.	Ammonia Free.	Albuminoid Total.	Albuminoid Dissolved.	Albuminoid Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
12.30 P.M., .	V. slight.	Cons.	.52	8.30	2.50	.0028	.0252	.0212	.0040	0.78	.0100	.0004	.68	-	Surface.	Above Riverside and below rapids.
12.30 P.M., .	V. slight.	Cons.	.52	8.80	2.80	.0028	.0236	.0196	.0040	0.79	.0060	.0003	.67	-	2 feet.	Above Riverside and below rapids.
1.25 P.M., .	V. slight.	Slight.	.50	7.30	2.50	.0052	.0228	.0204	.0024	0.78	.0080	.0002	.64	-	Surface.	Below railroad bridge, at Riverside.
1.30 P.M., .	V. slight.	V. slight.	.52	9.00	3.00	.0060	.0252	.0220	.0032	0.78	.0090	.0001	.67	-	4 feet.	Below railroad bridge, at Riverside.
2.20 P.M., .	V. slight.	V. slight.	.35	7.00	2.50	.0068	.0208	.0188	.0020	0.75	.0100	.0003	.56	-	Surface.	One mile below Weston bridge.
2.30 P.M., .	V. slight.	V. slight.	.38	7.00	2.40	.0060	.0224	.0180	.0044	0.76	.0100	.0002	.55	-	6 feet.	One mile below Weston bridge.
2.45 P.M., .	V. slight.	V. slight.	.32	7.00	3.00	.0068	.0204	.0176	.0028	0.74	.0100	.0003	.49	-	Surface.	At Waltham pumping station.
3.00 P.M., .	V. slight.	V. slight.	.35	7.20	2.70	.0076	.0184	.0160	.0024	0.74	.0110	.0002	.48	-	15 feet.	At Waltham pumping station.
3.20 P.M., .	V. slight.	V. slight.	.31	6.50	2.20	.0080	.0196	.0172	.0024	0.76	.0110	.0002	.44	-	Surface.	Above Waltham dam.
3.20 P.M., .	V. slight.	Cons.	.33	7.00	2.50	.0080	.0204	.0176	.0028	0.74	.0110	.0005	.44	-	7 feet.	Above Waltham dam.

TABLE No. 22. — *Charles River, at Waltham. — Oct. 16, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Depth.	Source.
							Albuminoid.								
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.			
12.20 P.M., . .	V. slight.	V. slight.	.30	7.00	2.50	.0084	.0208	.0196	.0012	.71	.0110	.0004	.48	Surface.	Elm Street bridge, left end.
12.20 P.M., . .	V. slight.	V. slight.	.32	7.10	2.30	.0076	.0200	.0196	.0004	.75	.0100	.0004	.50	Surface.	Elm Street bridge, centre.
12.30 P.M., . .	Slight.	Cons.	.35	7.10	2.40	.0400	.0272	.0252	.0020	.84	.0120	.0005	.55	Surface.	Elm Street bridge, right end.
12.50 P.M., . .	V. slight.	Cons.	.33	7.80	3.00	.0124	.0240	.0216	.0024	.78	.0150	.0005	.58	Surface.	Farwell Street bridge.
1.00 P.M., . .	V. slight.	Slight.	.32	7.80	3.00	.0104	.0248	.0204	.0044	.76	.0130	.0008	.51	4 feet.	Farwell Street bridge.
1.15 P.M., . .	Slight.	Cons.	.37	10.30	4.00	.0096	.0320	.0284	.0036	.84	.0160	.0008	.54	Surface.	At Bemis dam, from tail race of Ætna Mills.
1.25 P.M., . .	Slight.	Cons.	.33	9.20	3.70	.0084	.0368	.0256	.0112	.85	.0140	.0008	.52	2 feet.	At Bemis dam, from tail race of Ætna Mills.
1.35 P.M., . .	Slight.	Cons.	.34	9.00	3.70	.0080	.0348	.0280	.0068	.87	.0180	.0008	.58	Surface.	Below Bemis, at Howard Street.

TABLE No. 23. — *Charles River, Watertown Dam. — Oct. 17, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Source.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid.				Nitrates.	Nitrites.			
							Total.	Dissolved.	Suspended.						
7.45 A.M., .	V. slight.	Slight.	.28	7.70	3.00	.0152	.0232	.0184	.0048	0.84	.0150	.0009	.49	58.4	At Watertown dam.
8.45 A.M., .	V. slight.	Slight.	.30	8.70	3.00	.0128	.0216	.0184	.0032	0.84	.0140	.0007	.55	61.7	At Watertown dam.
9.45 A.M., .	V. slight.	Slight.	.30	7.70	3.00	.0100	.0220	.0188	.0032	0.82	.0160	.0008	.51	65.5	At Watertown dam.
10.45 A.M., .	V. slight.	V. slight.	.35	7.50	3.00	.0072	.0252	.0204	.0048	0.82	.0190	.0008	.51	67.0	At Watertown dam.
11.45 A.M., .	V. slight.	Slight.	.30	8.00	4.00	.0108	.0236	.0184	.0052	0.82	.0190	.0009	.90	71.6	At Watertown dam.
12.45 P.M., .	V. slight.	Slight.	.30	8.30	3.50	.0128	.0228	.0192	.0036	0.81	.0180	.0009	.52	73.3	At Watertown dam.
1.45 P.M., .	V. slight.	Slight.	.30	8.10	3.10	.0156	.0216	.0188	.0028	0.83	.0190	.0008	.50	73.8	At Watertown dam.
2.45 P.M., .	V. slight.	Slight.	.31	8.00	2.80	.0132	.0232	.0212	.0020	0.86	.0180	.0009	.57	71.6	At Watertown dam.
3.45 P.M., .	V. slight.	Slight.	.32	9.00	3.00	.0108	.0256	.0216	.0040	0.85	.0150	.0009	.58	69.5	At Watertown dam.
4.45 P.M., .	V. slight.	Slight.	.32	8.50	2.50	.0088	.0252	.0220	.0032	0.85	.0110	.0008	.60	67.2	At Watertown dam.

TABLE No. 24. — *Charles River, at Elm Street Bridge, Waltham, Surface. — Nov. 12, 1902.*

11.25 A.M., .	Slight.	Slight.	.70	10.00	4.00	.0075	.0280	-	-	0.72	-	-	-	-	Left end of bridge, below Boston Manufacturing Company's works.
11.30 A.M., .	V. slight.	V. slight.	.70	10.00	4.00	.0095	.0285	-	-	0.78	-	-	-	-	Centre of bridge, below Boston Manufacturing Company's works.
11.35 A.M., .	V. slight.	V. slight.	.80	9.40	3.00	.6400	.0440	-	-	1.10	-	-	-	-	Right end of bridge, below gas works.

Drainage, etc., entering the River at Waltham, Bemis, Watertown and below Watertown Dam.

The increased amount of organic matter in the salt-water basin, due to the water coming over Watertown dam, has already been mentioned. As the river comes down through Waltham, Bemis and Watertown, and passes the manufacturing establishments, it receives considerable polluting matter at times, as has been mentioned and shown on preceding tables (see series of September 5–11 and November 11, tables Nos. 14–16 and 30). Much matter settles out above Watertown dam to decay, but free oxygen has always been present in the water during the period of investigation.

Samples of the river water at or near drains from these industrial establishments have been collected, and the results of analyses are shown in following tables. In most instances where industrial wastes enter it has been impracticable to collect from the drain itself, but samples have been collected as near the point of discharge as possible. Some of these wastes contain much organic matter, but are comparatively small in volume; at times, however, they are noticeable upon the river, and the water is at places colored by them.

In the water collected below the dam considerable of the organic matter, prominent where the samples contain considerable fresh water, is due to the entrance of water more or less polluted from drains, sewer overflows, waste water pipes, or sewers from industrial establishments, etc. A few of the sources of pollution here are practically constant, while most of them are intermittent. One or two industrial establishments pour an almost continuous stream into the river, and the old and new Stony Brook channels and Muddy River flow continuously. The sewer overflows, however, only discharge in case of storms, and then cease. Generally, as one passes up the river, few entering streams are discovered. From the sewer overflows samples can be taken only at times of storm and when the tide is down.

Upon October 2, at low tide, samples were collected from all visible pipes or drains at that time discharging liquid into the river below Watertown dam, and the analyses of these samples are given in a following table. From five of these drains the liquid was of a character which would pollute the river, namely, from the Abattoir, from the starch factory, and from three culverts from the Speedway. Of these, the only decidedly offensive matter at that time was coming from the starch factory outlet.

Samples have been collected also from Broad Canal, and some pollution has been noticed there (see Table No. 32). Samples from back of Beacon Street have also been collected. At low tide there is often the appearance of sewage over a considerable area, and samples have been collected that, notwithstanding the admixture with sea water taking place, have shown large amounts of organic matter present. The following is an illustration: —

Sample collected off Beacon Street, Between Harvard and West Boston Bridges.

[Parts per 100,000.]

Turbidity.	Sediment.	Odor.	Ammonia.	
			Free.	Albuminoid.
Decided.	Heavy, black.	Slight, sewage.	.1310	.2520

TABLE No. 25. — *Drains Below Watertown Dam.* — *Sept. 22, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Source.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
8.40 A.M.,	V. slight.	Slight.	.23	17.30	4.90	.0260	.0180	.0100	.0080	1.10	.121	.0050	0.36	Howard's Pond, draining into Charles River.
11.00 A.M.,	V. slight	Heavy.	.46	14.80	4.40	.0570	.0300	.0276	.0024	1.38	.019	.0008	0.60	Tail race, below Galen Street bridge.
2.00 P.M.,	V. slight.	Decided.	.42	23.20	5.70	.0505	.0320	.0248	.0072	1.64	.029	.0010	0.52	Tail race, below Galen Street bridge.
2.15 P.M.,	Slight.	Heavy.	.44	34.60	10.60	.0180	.0320	.0285	.0035	2.28	.055	.0020	1.68	Tail race, below Galen Street bridge.

Low tide at 8.20 A.M.; high tide at 2.31 P.M.

TABLE NO. 26. — *Drains.* — *Oct. 2, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Approximate Flow (Gallons per Minute).	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.			
2.40 P.M.,	V. slight.	V. slight.	.11	0.0190	0.0180	1560	Tidal flow.	Open ditch, above Captain's Island bath-house.
3.00 P.M.,	V. slight.	V. slight.	.08	0.0410	0.0160	1480	10	Ten-inch pipe from Cambridge Electric Light Company.
4.30 P.M.,	Decided.	Cons.	.21	0.1535	0.0420	780	1,500	Above Abattoir, off North Beacon Street.
4.40 P.M.,	Decided.	Cons.	-*	2.2800	2.8400	360	8	Just above Abattoir, from starch factory.
4.50 P.M.,	Slight.	Cons.	.07	0.0255	0.0330	510	5	Ten-inch pipe, outlet from Abattoir.
5.00 P.M.,	Slight.	Cons.	.10	0.5400	0.0510	735	200	Culvert at Speedway, below lumber yard.
5.00 P.M.,	Slight.	Cons.	.09	0.1060	0.0295	1050	10	Drain from Speedway, opposite Cambridge cemetery.
5.20 P.M.,	Decided.	Cons.	.31	0.1110	0.0325	935	-	Drain from Speedway, farther down.
5.40 P.M.,	V. slight.	Slight.	.17	0.0455	0.0275	840	2	Drain below Cambridge dispensary.

Low tide at 5.45 P.M.

* Turbid.

TABLE No. 27. — *Charles River, above Watertown Dam. — Oct. 3, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.		Nitrates.	Nitrites.				
12.00 M., .	V. slight.	Slight.	.30	8.50	2.50	.1312	.0260	.0248	.0012	0.82	.0100	.0002	.52	58.7	Surface.	Charles River, at Elm Street bridge, Waltham, below gas works.
12.30 P.M., .	V. slight.	Slight.	.01	33.00	10.50	.0336	.0104	.0072	.0032	5.10	.8000	.0010	.14	–	Surface.	Thirty-inch sewer entering Charles River at Elm Street bridge.
12.45 P.M., .	Decided.	Cons.	.33	9.30	2.50	.0332	.0304	.0252	.0052	1.00	.0220	.0007	.63	71.1	Surface.	Charles River, at Farwell Street bridge, below bleachery.
12.50 P.M., .	V. slight.	Cons.	.34	8.00	2.80	.0328	.0252	.0236	.0016	0.88	.0200	.0008	.50	71.2	3 feet.	Charles River, at Farwell Street bridge, below bleachery.
1.35 P.M., .	Decided.	Cons.	.40	11.70	3.00	.0256	.0384	.0312	.0072	0.90	.0200	.0012	.80	54.9	Surface.	Race of Ætna Woolen Mills, Bemis.

TABLE No. 28. — *Charles River, below Watertown Dam. — Oct. 10, 1902.*

Time of Collection.	Turbidity.	Sediment.	Color.	Residue Total.	Loss on Ignition.	Ammonia Free.	Albuminoid Total.	Dissolved.	Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Dissolved Oxygen.	Depth.	Source.
4.30 P.M., .	V. slight.	V. slight.	.31	–	–	.0128	.0268	–	–	1.08	–	–	–	–	Surface.	Charles River, at Watertown dam, spillway.
4.15 P.M., .	Slight.	Cons.	–*	–	–	.0108	.0296	–	–	3.70	–	–	–	–	Surface.	Race from Lewando's dye-house.
4.45 P.M., .	V. slight.	V. slight.	.30	–	–	.0124	.0288	–	–	1.15	–	–	–	–	Surface.	Charles River, at Watertown, at gas works.
4.45 P.M., .	V. slight.	V. slight.	.28	–	–	.0108	.0260	–	–	7.60	–	–	–	–	1 foot.	Charles River, at Watertown, at gas works.

* Poor color.

TABLE NO. 29. — *Charles River, at Bemis Dam. — Oct. 16, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Depth.	Source.
							Albuminoid.								
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.			
1.15 P.M., .	Slight.	Cons.	.37	10.30	4.00	.0096	.0320	.0284	.0036	0.84	.0160	.0008	0.54	Surface.	Tail race, Ætna Mills.
1.25 P.M., .	Slight.	Cons.	.33	9.20	3.70	.0084	.0368	.0256	.0112	0.85	.0140	.0008	0.52	2 feet.	Tail race, Ætna Mills.

TABLE NO. 30. — *Nov. 11, 1902.*

Time of Collection.	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Depth.	Source.
11.15 A.M., .	Decided.	Cons.	.80	27.00	8.00	.0180	.0310	–	–	0.85	–	–	1.76	–	Watertown, race from Union Bag and Paper Company.
11.20 A.M., .	Decided.	Cons.	–*	21.00	8.00	.0270	.0450	–	–	1.95	–	–	2.20	–	Watertown, race from Lewando's dye-house.
11.40 A.M., .	Decided.	Cons.	.70	14.00	5.60	.0235	.0355	–	–	1.15	–	–	1.22	–	Watertown, race below Walker & Pratt Manufacturing Co.'s storehouse.
11.45 A.M., .	Slight.	Cons.	.70†	15.00	5.00	.0200	.0300	–	–	0.93	–	–	0.96	–	Watertown, race below Walker & Pratt Manufacturing Co.'s storehouse.
1.25 P.M., .	Slight.	Slight.	1.00†	13.80	6.00	.0248	.0508	–	–	1.70	–	–	1.68	–	Bemis, at Farwell Street bridge, below bleachery.
1.00 P.M., .	V. slight.	Cons.	1.04	23.40	6.40	.0188	.0320	–	–	0.78	–	–	0.90	–	Bemis, race of Ætna Mills.
1.10 P.M., .	Slight.	Slight.	.72	10.40	4.40	.0225	.0465	–	–	0.82	–	–	1.30	–	Bemis, race of Ætna Mills.
2.00 P.M., .	Decided.	Cons.	–	24.00	8.00	.0335	.0460	–	–	1.25	–	–	1.80	–	Watertown, race from Lewando's.
2.05 P.M., .	Decided.	Cons.	–‡	24.00	9.00	.0270	.0470	–	–	2.85	–	–	1.58	–	Watertown, race from Lewando's.

* Black. † Turbid. ‡ Blue.

TABLE No. 31. — *Charles River, at Elm Street Bridge, Waltham, Surface.* — *Nov. 12, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Bacteria per c. c.	Source.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.			
11.25 A.M., . . .	Slight.	Slight.	.70	10.00	4.00	.0075	.0280	-	-	.72	-	Left end of bridge.
11.30 A.M., . . .	V. slight.	V. slight.	.70	10.00	4.00	.0095	.0285	-	-	.78	-	Centre of bridge.
11.35 A.M., . . .	V. slight.	V. slight.	.80	9.40	3.00	.6400	.0440	-	-	1.10	-	Right end of bridge, gas works waste.

TABLE No. 32. — *Broad Canal, Cambridge, Surface.* — *Sept. 15, 1902.*

Time of Collection.	Turbidity.	Sediment.	Color.	Residue Total.	Loss on Ignition.	Ammonia Free.	Albuminoid Total.	Dissolved.	Suspended.	Chlorine.	Bacteria per c. c.	Source.
1.30 P.M., . . .	-	-	-	-	-	.0715	.1255	.0172	.1083	1605.00	8,900	Between Third and Fourth Street bridges.
1.30 P.M., . . .	-	-	-	-	-	.0452	.0212	-	-	1605.00	1,200	Between Second and Third Street bridges.
1.30 P.M., . . .	-	-	-	-	-	.0520	.0220	.0148	.0072	1602.00	22,400	Between First and Second Street bridges.

Low tide at 3.28 P.M.

Turbidity of Water of Stony Brook at Different Locations.

1. Forest Hills.
2. Williams Street below Entrance of Brewery Waste.
3. Stony Brook Outlet.
4. Muddy River Outlet.

Stony Brook and the Fenways.

The largest stream entering the river below Watertown dam is that from the Fenways. This consists of water that comes down through the new Stony Brook conduit. Muddy River, the outlet of Jamaica Pond, enters by a separate conduit. The old Stony Brook channel brings down considerable ground water and about 2.5 million gallons per day of metropolitan water that has been used for condensation. This flows out into the Charles through the wooden conduit at the side of the Fenway outlet. The character of each of these streams has been determined frequently during the period of investigation. Samples of water from the new Stony Brook conduit and from the brook as far up as Forest Hills have also been collected and examined (see series of September 1, 2, 3, 10 and 11, tables Nos. 33, 34 and 35). At or above Forest Hills station the water in Stony Brook under normal summer conditions is clear, low in color, with little organic matter, and practically odorless. As it comes out from the new conduit into the Fens at Huntington Avenue bridge in dry weather its odor is decidedly unpleasant and at times offensive, and the organic matter present is several times as great as above Forest Hills, and in a putrescent state. The surface water in the upper portion of the Fens Basin near this outlet, while at times containing free oxygen in summer, is generally lacking in this respect, and the under layers seldom contain free oxygen in summer. In the Fens basin near the Stony Brook outlet there are heavy deposits of putrescent mud, from which bubbles of marsh gas are constantly rising in great abundance, and the water is often impregnated with the odor of hydrogen sulphide. The samples collected upon September 12 may be considered as representative of the water at this point (see Table No. 36).

Studying the reasons for the change in the character of the water of Stony Brook between Forest Hills and the Fens, we find that just below Forest Hills station at Williams Street a brewery discharges waste into the stream, and that an outlet from another brewery enters the conduit. This matter, like all brewery wastes, is highly putrescent, and at times has a sour and offensive odor. Upon October 9 a series of samples was collected, showing that the water in the conduit at Lotus Place bridge above the entrance of this brewery waste contained little organic matter, while a sample collected below the brewery at Williams Street contained 3½ times as much. Below the Sturtevant blower works another sample was collected, and, while the amount of organic matter had not increased, putrefaction had begun, the sample had a decidedly offensive odor, and the dissolved oxygen had begun to disappear. These analyses follow: —

Stony Brook.

[Parts per 100,000.]

Location.	Ammonia.		Chlorine.	Dissolved Oxygen, Per Cent. Saturation.
	Free.	Albuminoid.		
At Arborway bridge,	.0256	.0240	7.35	–
At Lotus Place bridge,	.0240	.0248	5.20	–
At Williams Street bridge,	.0300	.0800	1.75	69.5
Below Sturtevant blower works,	.0560	.0730	1.90	41.9

This change in the character of the water, due to the entrance of the waste, was observed at other times; and upon October 25 a second series of samples from the same locations was taken, and with even more striking results as to the addition of organic matter at this place. The albuminoid ammonia in the water below the brewery outlet on this date was sixty-five times as high as that in the water above; that is, it was nearly twice as high as in average sewage, and of a kind easily and quickly rotting. The analyses follow: —

Stony Brook.

[Parts per 100,000.]

Location.	Ammonia.		Chlorine.
	Free.	Albuminoid.	
At Arborway bridge,	.0160	0.0172	2.90
At Lotus Place bridge,	.0168	0.0160	5.30
At Williams Street bridge,	.0980	1.1000	1.70
Where it enters Sturtevant blower works,	.0700	0.1340	1.70
After passing through Sturtevant blower works,	.1280	0.1540	1.90

Upon each of these days samples for bacterial examination were also collected, and upon October 9 the bacteria above the entrance of the waste were 550 and below the entrance of the waste 31,000 per c. c. Upon October 25 the numbers were 1,400 and 90,000 per c. c. respectively. Samples collected upon other days gave similar results.

Upon September 30 a trip through nearly the entire length of the covered conduit, often called "the commissioners' channel," was made, and a number of samples were collected. This journey revealed the condition of this large new conduit to be anything but well cared for. To say nothing of the various heaps of stones and bricks, clothing, carpets, straw matting, old shoes, bundles, dead cats, etc., there was through a large portion of the conduit a layer of deep, slimy mud, through which one had considerable difficulty in walking. Upon this day samples were collected from all drains entering the covered conduit from which anything was found flowing in this dry-weather period, and a study of the table will show five in all. From four of these water considerably more polluted than that flowing in the channel was collected, but the streams entering were very small. The analyses follow: —

Samples from New Stony Brook Conduit.

[Parts per 100,000.]

Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Residue on Evaporation. Fixed.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Oxygen Consumed.	Source.
14.00	5.50	8.50	0.0160	.0120	1.15	0.37	Conduit, above entrance of brewery wastes.
17.50	7.00	10.50	0.0760	.0480	1.61	1.40	Conduit, below entrance of upper brewery wastes.
19.00	6.00	13.00	0.0720	.1160	1.56	2.44	Conduit.
36.00	18.50	17.50	0.0720	.0880	1.61	1.38	Conduit.
62.70	17.00	45.70	0.2000	.1100	19.80	3.16	Conduit.
34.20	8.70	25.50	0.0800	.0295	8.20	0.50	Conduit.
85.60	19.00	66.60	0.1360	.0740	33.60	1.06	Conduit.
5.80	2.30	3.50	0.0012	.0080	0.38	0.33	Drain entering conduit.
23.50	7.50	16.00	0.2480	.0780	1.93	1.88	Drain entering conduit.
58.50	15.80	42.70	1.4400	.3720	19.20	3.32	Drain entering conduit.
34.90	11.00	23.90	0.2000	.0190	4.20	0.48	Drain entering conduit.
65.30	15.80	49.50	0.0960	.0900	24.40	1.04	Fens.

Many analyses of the water flowing into the river on different days from the outlet of the Fens, from the old and new Stony Brook outlets and from Muddy River outlet, have also been made and are shown on the tables. Examining these results, it will be seen that there is little difference in polluting character between the flow from the old and that from the new outlets. Both Stony Brook outlets have discharged during the period of investigation water which may be called weak sewage, but which nevertheless is distinctly sewage in the broad sense of the word, including both domestic and industrial wastes and containing at different times approximately from one-eighth to one-third as much organic matter, determined as albuminoid ammonia, as average sewage. The water flowing from the Muddy River outlet is at times of about the same degree of pollution.

TABLE No. 33. — *Stony Brook.* — *Sept. 1, 1902.*

[Parts per 100,000.]

Time of Collection.	Date of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Oxygen Consumed.	Depth.	Source.
		Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.				
4.30 P.M., .	-	-	-	-	-	-	.2270	.0650	.0375	.0275	280.00	1.32	.1 foot.	At Fenway bridge open channel, below Huntington Avenue.
4.25 P.M., .	-	-	-	-	-	-	.0290	.0685	.0500	.0185	1360.00	4.40	2 feet.	At Fenway bridge open channel, below Huntington Avenue.
6.40 P.M., .	-	-	-	-	-	-	.0100	.0260	-	-	1.48	-	-	Forest Hills, entrance to covered conduit at crossing of railroad and Washington Street.
6.40 P.M., .	-	-	-	-	-	-	.0116	.0264	-	-	1.25	-	-	Forest Hills, entrance to covered conduit at crossing of railroad and Washington Street.

Low tide in Charles at 4.27 P.M. Low water in Fens basin is 4 hours 30 minutes later.

TABLE No. 34. — *Stony Brook.*

Time of Collection.	Date of Collection.	Turbidity.	Sediment.	Color.	Residue Total.	Loss on Ignition.	Ammonia Free.	Albuminoid Total.	Albuminoid Dissolved.	Albuminoid Suspended.	Chlorine.	Oxygen Consumed.	Depth.	Source.
	1902.													
12.40 P.M., .	Sept. 2,	Slight.	Cons.	.15	19.00	6.80	.0046	.0208	.0168	.0040	1.33	0.30	-	Entrance to covered conduit at crossing of railroad and Washington Street, Forest Hills.
2.09 P.M., .	Sept. 2,	Decided.	Cons.	.36	43.50	11.00	.0235	.0725	.0320	.0405	1.70	0.72	-	New Stony Brook conduit opposite Hoffman Street.
-	Sept. 2,	Slight.	Cons.	-	829.30	49.00	.2700	.1110	-	-	386.00	-	-	New conduit at outlet to Fens, at Huntington Avenue.
9.23 P.M., .	Sept. 3,	Decided.	Cons.	.23	176.30	5.00	.1560	.1640	.0420	.1220	100.00	0.98	-	Old Stony Brook channel at Linden Park Street bridge.
8.30 P.M., .	Sept. 3,	Decided.	Cons.	.26	39.00	3.50	.1580	.0740	.0350	.0390	18.20	0.50	-	Old Stony Brook channel at Fens gate house.

September 2, high tide in Charles at 11.06 A.M.; in Fens, about 1.06 P.M. September 3, low tide in Charles at 6.06 P.M.; in Fens, about 10.30 P.M.

TABLE NO. 35. — *Fens Basin.*

[Parts per 100,000.]

Time of Collection.	Date of Collection.	Appearance.			Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
		Turbidity.	Sediment.	Color.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.		Nitrates.	Nitrites.				
	1902.														
5.00 P.M., .	Sept. 10,	Decided.	Cons.	.29	.1800	.0590	.0380	.0210	166.80	.0170	.0110	1.14	34.1	Surface.	Near outlet of Stony Brook, below Huntington Avenue.
5.00 P.M., .	Sept. 10,	Decided.	Cons.	.14	.0700	.0515	.0270	.0245	1270.00	.0020	.0010	2.74	39.9	1½ feet.	Near outlet of Stony Brook, below Huntington Avenue.
10.00 A.M., .	Sept. 11,	Decided.	Cons.	.18	.0570	.0965	.0425	.0540	356.00	.0020	.0140	1.58	55.7	Surface.	First bridge above Commonwealth Avenue bridge.
10.00 A.M., .	Sept. 11,	Decided.	Cons.	.24	.3500	.0670	.0330	.0340	1385.00	.0000	.0000	3.60	0.0	4 feet.	First bridge above Commonwealth Avenue bridge.
4.00 P.M., .	Sept. 10,	Decided.	Cons.	.15	.0148	.0796	.0320	.0476	955.00	.0000	.0014	2.18	–	Surface.	Commonwealth Avenue bridge.
4.00 P.M., .	Sept. 10,	Decided.	Cons.	.20	.1860	.0444	.0256	.0188	1380.00	.0000	.0000	3.78	0.0	6 feet.	Commonwealth Avenue bridge.

September 10, high tide in Charles at 5.28 P.M.; in Fens, about 7.28 P.M.
September 11, low tide in Charles at 12.09 P.M.; in Fens, about 4.39 P.M.

TABLE NO. 36. — *Fens Basin.* — *Sept. 12, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Residue on Evaporation.		Ammonia.				Chlorine.	Dissolved Oxygen, Per Cent. Saturation.	Bacteria per c. c.	Depth.	Source.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.					
10.05 A.M., . . .	Decided.	Cons.	.12	271.40	45.00	.1350	.0420	.0255	.0165	133	0.0	108,000	Surface.	At outlet of Stony Brook.
10.05 A.M., . . .	Decided.	Heavy.	.19	3001.20	804.00	.2700	.0850	.0370	.0480	1290	0.0	4,500	3 feet.	At outlet of Stony Brook.
10.50 A.M., . . .	Decided.	Cons.	.17	336.20	67.60	.1350	.0415	.0225	.0190	144	0.0	181,000	Surface.	First bridge below Huntington Avenue.
11.00 A.M., . . .	Slight.	Cons.	.16	2298.00	197.00	.0720	.0560	.0340	.0220	1285	20.6	1,500	2 feet.	First bridge below Huntington Avenue.
11.45 A.M., . . .	Slight.	Cons.	.18	913.40	122.00	.1000	.0710	.0430	.0280	344	2.6	131,000	Surface.	Second bridge below Huntington Avenue.
11.45 A.M., . . .	Slight.	Cons.	.19	2983.00	787.00	.3300	.0650	.0390	.0260	1365	0.0	2,500	4 feet.	Second bridge below Huntington Avenue.
12.30 P.M., . . .	Decided.	Cons.	.20	1039.00	100.40	.0520	.1015	.0610	.0405	565	74.0	23,500	Surface.	Commonwealth Avenue bridge.
12.30 P.M., . . .	V. slight.	Slight.	.10	2774.40	589.00	.1200	.0470	.0290	.0180	1365	0.0	2,000	5½ feet.	Commonwealth Avenue bridge.

High tide in Charles at 6.48 A.M.; in Fens basin, about 8.48 A.M.
Low tide in Charles at 1.01 P.M.; in Fens basin, about 5.31 P.M.

TABLE NO. 37. — *Fens Basin.* — *Sept. 23, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.				Chlorine.	Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.					
2.00 P.M., ...	Slight.	Cons.	.22	.1152	.0348	.0248	.0100	58.25	0.70	0.0	Surface.	At outlet of Stony Brook, Huntington Avenue.
2.00 P.M., ...	Decided.	Cons.	.23	.2440	.0500	.0320	.0180	1395.00	3.20	0.0	4 feet.	At outlet of Stony Brook, Huntington Avenue.
2.30 P.M., ...	Decided.	Cons.	.23	.1280	.0588	.0312	.0276	80.75	0.81	0.0	Surface.	First bridge below Huntington Avenue.
2.30 P.M., ...	Decided.	Cons.	.23	.1160	.0845	.0290	.0555	1410.00	2.80	0.0	3 feet.	First bridge below Huntington Avenue.
3.00 P.M., ...	Decided.	Cons.	.24	.1220	.0890	.0430	.0460	312.40	1.61	8.0	Surface.	Second bridge below Huntington Avenue.
3.00 P.M., ...	Decided.	Cons.	.15	.2560	.0360	.0220	.0140	1508.00	1.72	0.0	5 feet.	Second bridge below Huntington Avenue.
3.30 P.M., ...	Decided.	Cons.	.24	.0900	.0860	.0540	.0320	490.00	1.95	77.3	Surface.	Commonwealth Avenue bridge.
3.30 P.M., ...	V. slight.	Slight.	.09	.0400	.0276	.0192	.0084	1520.00	2.21	64.1	7 feet.	Commonwealth Avenue bridge.

High tide in Charles at 3.26 P.M.; in Fens basin, about 5.26 P.M.

TABLE No. 38. — *New Stony Brook Conduit.* — *Sept. 30, 1902.*

[Parts per 100,000.]

Time of Collection.	Residue on Evaporation.		Ammonia.		Chlorine.	Oxygen Consumed.	Approximate Quantity flowing, Cubic Feet per Second.	Source.
	Total.	Loss on Ignition.	Free.	Albuminoid.				
12.15 P.M., . . .	14.00	5.50	.0160	.0120	1.15	0.37	2.00	Conduit, above entrance supplementary channel at Boylston Avenue.
– –	17.50	7.00	.0760	.0480	1.61	1.40	3.50	Conduit, below supplementary channel.
12.26 P.M., . . .	19.00	6.00	.0720	.1160	1.56	2.44	3.50	Conduit, 1,000 feet below supplementary channel, Hoffman Street.
– –	36.00	18.50	.0720	.0880	1.61	1.38	3.50	Conduit, 1, 700 feet below supplementary channel, Ritchie Street.
– –	62.70	17.00	.2000	.1100	19.80	3.16	3.50	Conduit, 4,000 feet below supplementary channel, below New Heath Street.
1.10 P.M., . . .	34.20	8.70	.0800	.0295	8.20	0.50	0.00	Brick sewer, west side, above Tremont Street.
– –	85.60	19.00	.1360	.0740	33.60	1.06	4.00	Easterly of double channels, Parker and Ward streets.
11.00 A.M., . . .	5.80	2.30	.0012	.0080	0.38	0.33	0.10	Twenty-inch pipe, just below gate house, Roxbury Crossing.
11.00 A.M., . . .	23.50	7.50	.2480	.0780	1.93	1.88	0.05	Thirty-inch brick sewer from old conduit in Cedar Street.
– –	58.50	15.80	1.4400	.3720	19.20	3.32	0.30	Five-foot brick sewer overflow of Stony Brook valley sewer near Heath Street.
11.25 A.M., . . .	34.90	11.00	.2000	.0190	4.20	0.48	0.05	Brick sewer, 4 feet 3 inches diameter, Columbus Avenue and Centre Street.
1.35 P.M., . . .	65.30	15.80	.0960	.0900	24.40	1.04	4.00	Outlet of new Stony Brook conduit in Fens.

High tide in Charles at 9.58 A.M.; in Fens basin, about 11.58 A.M.
Low tide in Charles at 4.10 P.M.; in Fens basin, about 8.40 P.M.

TABLE NO. 39. — *Outlet of New Stony Brook, and Fens Basin.* — *Oct. 1, 1902.*

[Parts per 100,000.]

TIME OF COLLECTION.	APPEARANCE.			RESIDUE ON EVAPORATION.		AMMONIA.				Chlorine.	NITROGEN AS		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Total.	Loss on Ignition.	Free.	ALBUMINOID.				Nitrates.	Nitrites.				
							Total.	Dissolved.	Suspended.							
4.00 P.M., .	Decided.	Heavy, earthy.	-	660.40	11.80	.3200	.1550	.0800	.0750	300.00	.0000	.0012	4.60	12.9	Surface.	Outlet of conduit into open channel at Huntington Avenue.
4.00 P.M., .	Decided.	Cons., earthy.	.28*	3046.00	685.00	.3200	.0470	.0270	.0200	1355.00	.0000	.0000	6.30	0.0	3 feet.	Outlet of conduit into open channel at Huntington Avenue.
4.30 P.M., .	Decided.	Heavy, earthy.	-	609.00	111.00	.3400	.1950	.0800	.1150	266.00	.0020	.0024	5.00	9.5	Surface.	First bridge over open channel below Huntington Avenue.
4.30 P.M., .	Decided.	Heavy, earthy.	.32*	2771.60	611.20	.3000	.0750	.0350	.0400	1245.00	.0000	.0000	5.90	0.0	3 feet.	First bridge over open channel below Huntington Avenue.

Low tide in Charles at 4.49 P.M.; in Fens basin, about 9.19 P.M. * Turbid.

TABLE NO. 40. — *New Stony Brook, Surface.* — *Oct. 9, 1902.*

10.00 A.M., .	V. slight.	Slight.	.39	-	-	.0256	.0240	-	-	7.35	-	-	-	-	-	Arborway bridge.
10.10 A.M., .	V. slight.	Slight.	.33	-	-	.0240	.0248	-	-	5.20	-	-	-	-	-	Lotus Place bridge.
10.30 A.M., .	Decided.	Cons.	.29	-	-	.0300	.0800	-	-	1.75	-	-	-	69.5	-	Williams Street bridge.
10.40 A.M., .	Decided.	Cons.	.23	-	-	.0560	.0730	-	-	1.90	-	-	-	41.9	-	Green Street, Jamaica Plain.

Low tide in Charles at 10.36 A.M.; in Fens basin, about 3.06 P.M.

TABLE NO. 41. — *Fens Basin.* — *Oct. 14, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.				
12.15 P.M., ...	V. slight.	Slight.	.59*	.0620	.0310	14.70	65.6	Surface.	First bridge below outlet of Stony Brook.
12.15 P.M., ...	V. slight.	V. slight.	.45*	.0640	.0325	16.90	63.5	1 foot.	First bridge below outlet of Stony Brook.
12.30 P.M., ...	Slight.	Slight.	.16	.2000	.0410	1093.00	0.0	3 feet.	First bridge below outlet of Stony Brook.
1.00 P.M., ...	Decided.	Cons.	.50	.0590	.0550	93.50	44.7	Surface.	Second bridge below outlet of Stony Brook.
1.00 P.M., ...	Decided.	Cons.	.35	.0710	.0530	355.00	41.7	1 foot.	Second bridge below outlet of Stony Brook.
1.10 P.M., ...	Slight.	Cons.	.21	.0850	.0300	913.00	34.2	2 feet.	Second bridge below outlet of Stony Brook.
1.15 P.M., ...	Slight.	Slight.	.18	.2600	.0200	1183.00	0.0	4 feet.	Second bridge below outlet of Stony Brook.
2.00 P.M., ...	Decided.	Cons.	.23	.1650	.0550	560.00	29.4	Surface.	Stony Brook, across Beacon Street from Fens.
2.00 P.M., ...	Decided.	Cons.	.20	.1420	.0390	710.00	29.7	1 foot.	Stony Brook, across Beacon Street from Fens.
2.45 P.M., ...	Slight.	Cons.	.21	.1170	.0450	350.00	-	Surface.	Old Stony Brook conduit.

Low tide in Charles at 2.55 P.M.; in Fens basin about 7.25 P.M.

* Turbid.

TABLE NO. 42. — *Stony Brook.* — *Oct. 25, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.			
10.00 A.M.,	V. slight.	Slight.	.27	.0160	0.0172	2.90	-	At Arborway bridge.
10.10 A.M.,	V. slight.	Slight.	.27	.0168	0.0160	5.30	-	At Lotus Place bridge.
10.30 A.M.,	Decided.	Cons.	-*	.0980	1.1000	1.70	-	At Williams Street bridge.
10.40 A.M.,	Decided.	Cons.	-*	.0700	0.4340	1.70	-	Where it enters Sturtevant blower works yard.
10.45 A.M.,	Slight.	Cons.	-*	.1280	0.1540	1.90	-	After passing through Sturtevant blower works.

TABLE NO. 43. — *Fens Basin.* — *Oct. 29, 1902.*

Time of Collection.	Turbidity.	Sediment.	Color.	Free.	Albuminoid.	Chlorine.	Depth.	Source.
11.30 A.M.,	Decided.	Cons.	-*	.1100	0.0610	407.00	Surface.	At Brookline Avenue gate house.
11.30 A.M.,	V. slight.	V. slight.	.13	.0512	0.0184	1430.00	7 feet.	At Brookline Avenue gate house.
11.50 A.M.,	Decided.	Cons.	-*	.1280	0.0690	286.00	Surface.	First stone bridge below entrance on Brookline Ave.
11.50 A.M.,	V. slight.	V. slight.	.18	.0560	0.0228	1410.00	7 feet.	First stone bridge below entrance on Brookline Ave.
12.00 M.,	Slight.	Slight.	-*	.0540	0.0490	18.20	Surface.	Stony Brook, at entrance of Muddy River.
12.00 M.,	Slight.	Cons.	-*	.0630	0.0620	69.50	2 feet.	Stony Brook, at entrance of Muddy River.

High tide in Charles at 9.37 A.M.; in Fens basin, about 11.37 A.M.

* Turbid.

TABLE No. 44. — *Fens Basin.* — *Nov. 8, 1902.*

[Parts per 100,000]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Dissolved Oxygen, Per Cent. Saturation.	Depth.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.				
9.20 A.M.,	V. slight.	Slight.	.20	.2176	.0548	530.00	65.0	Surface.	Brookline Avenue gate house.
9.30 A.M.,	V. slight.	V. slight.	.13	.0432	.0228	1295.00	55.3	6 feet.	Brookline Avenue gate house.
9.45 A.M.,	Slight.	Cons.	.21	.3040	.0916	305.00	47.6	Surface.	Between Brookline Avenue and first stone bridge.
9.55 A.M.,	None.	V. slight.	.11	.0464	.0236	1310.00	53.0	6 feet.	Between Brookline Avenue and first stone bridge.
10.10 A.M.,	Slight.	Slight.	.20	.3200	.0868	240.00	39.3	Surface.	Stone bridge below Brookline Avenue.
10.20 A.M.,	V. slight.	V. slight.	.12	.0608	.0232	1330.00	44.4	6 feet.	Stone bridge below Brookline Avenue.
10.35 A.M.,	Slight.	Slight.	.20	.2880	.1104	195.00	26.5	Surface.	Opposite "Italian palace."
10.50 A.M.,	V. slight.	V. slight.	.10	.0640	.0252	1320.00	42.3	5 feet.	Opposite "Italian palace."
11.15 A.M.,	Decided.	Cons.	.22	.2720	.1048	180.00	32.0	Surface.	Between "Italian palace" and Stony Brook channel.
11.30 A.M.,	V. slight.	Slight.	.13	.1088	.0312	1275.00	17.0	5 feet.	Between "Italian palace" and Stony Brook channel.
11.55 A.M.,	Decided.	Cons.	.28	.2400	.0752	74.00	47.7	Surface.	Where Muddy River enters Stony Brook.
12.00 M.,	V. slight.	Slight.	.16	.0928	.0352	995.00	44.5	2 feet.	Where Muddy River enters Stony Brook.
12.20 P.M.,	Slight.	Slight.	.27	.1760	.0448	64.50	47.8	Surface.	Stony Brook, opposite Muddy River.
12.35 P.M.,	V. slight.	Slight.	.27	.1488	.0420	38.50	60.3	Surface.	Stony Brook, above Muddy River.
12.45 P.M.,	V. slight.	V. slight.	.11	.1320	.0280	1290.00	0.0	4 feet.	Stony Brook, above Muddy River.
1.00 P.M.,	Slight.	Slight.	.21	.2240	.0784	212.00	46.6	Surface.	Stony Brook, below Muddy River.
1.15 P.M.,	V. slight.	Slight.	.12	.0992	.0356	1105.00	31.8	2 feet.	Stony Brook, below Muddy River.
1.40 P.M.,	V. slight.	Cons.	.16	.2000	.0540	595.00	33.0	Surface.	Third bridge below outlet of Stony Brook.
1.55 P.M.,	V. slight.	Cons.	.10	.0704	.0464	1120.00	54.9	Surface.	At Beacon Street tide gate.
2.10 P.M.,	V. slight.	Slight.	.09	.0928	.0328	1305.00	9.5	5 feet.	At Beacon Street tide gate.

Low tide in Charles at 10.48 A.M.; in Fens basin, about 3.18 P.M. High tide in Charles at 4.55 P.M.; in Fens basin, about 6.55 P.M.

424 425 426 427

Turbidity of Water of Charles River at Stations at Harvard Bridge at Time of Storm and Low Tide.

424. 150 feet from South Bank.
425. Half way between South Bank and Draw.
426. At Draw.
427. Half way between Draw and North Bank.

424 425 426 427

Same after 24 Hours Sedimentation.

TABLE NO. 45. — *Stony Brook. — Nov. 10, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.		
11.15 A.M.,	None.	V. slight.	.25	.0224	.0176	1.70	At Lotus Place, Forest Hills.
11.25 A.M.,	V. slight.	Cons., hop-hulls.	.27	.0416	.0220	1.70	At Williams Street, Forest Hills.
11.35 A.M.,	Slight.	Cons.	.24	.0768	.0448	1.70	At Green Street, Jamaica Plain.

Low tide in Charles at 12.37 P.M.; in Fens basin, about 5.07 P.M.

TABLE NO. 46. — *Stony Brook, at Forest Hills. — Nov. 13, 1902.*

[Parts per 100,000.]

Time of Collection.	Appearance.			Ammonia.		Chlorine.	Source.
	Turbidity.	Sediment.	Color.	Free.	Albuminoid.		
3.05 P.M.,	V. slight.	Slight.	.35	.0300	.0236	1.70	At Lotus Place.
3.15 P.M.,	Slight.	Cons.	.38	.0580	.0368	1.90	At Williams Street.

Low tide in Charles at 3.14 P.M.; in Fens basin, about 7.44 P.M.

APPEARANCE OF THE LOWER CHARLES RIVER OR TIDAL ESTUARY.

Observations of the river have shown that at the beginning of a storm, especially when the tide is low and the overflows are discharging, much sewage is passed into the river, together with paper, street washings and various other matters, which give the river a very dirty appearance over fairly large areas. On the portions of the river, however, which become turbid and muddy in appearance, the organic matter and silt are in a fairly thin layer of surface water.

Upon October 28, after a storm of about sixteen hours' duration, when the sewer overflows were still discharging slightly, and large streams were coming from Muddy River and the Fenways, a series of surface samples was collected across the section of the river covered by Harvard bridge (see table below). The river was very turbid from the south bank two-thirds the distance to the draw, and, while the turbidity across the remainder of the section was noticeable when looking at the river, the water from the surface collected in glass bottles was comparatively clear (see photographs). The amount of organic matter in the turbid samples was comparatively high (see table below), but, as mentioned, the layer of turbid fresh water over the salt was very thin. These samples were collected near low tide, and the turbidity and organic matter present in the sample, taken two-thirds the distance from the south end of the bridge to the draw, were partly due to the water having washed through and over mud banks above the bridge, the

organic matter and mud taken up in this way increasing the turbidity very noticeably. Other observations and samples have shown the thinness of the turbid layer.

Analyses of Samples collected from Harvard Bridge, Oct. 28, 1902.

[Parts per 100,000.]

Turbidity.	Sediment.	Color.	Odor.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Source.
Decided.	Heavy.	.18	Faintly unpleasant.	.0860	.0750	887.50	One hundred and fifty feet from south end of bridge.
Decided.	Heavy.	.21	Faintly unpleasant.	.1040	.1340	830.00	Two-thirds the distance to the draw.
Slight.	Slight.	.15	Faintly unpleasant.	.0295	.0210	1310.00	At draw.
V. slight.	V. slight.	.10	Faintly unpleasant.	.0240	.0172	1350.00	Between draw and north end of bridge.

Summary of the Condition of the River, as shown by Examinations, together with Notes on Dissolved Oxygen.

Summarizing what has been said, it appears that the main portion of the tidal estuary is now at high tide in the summer season practically filled with salt harbor water containing a small proportion of fresh water, the proportion of fresh water increasing rapidly in the upper reaches of the estuary. At low tide the fresh water is more prominent over the entire basin than at high tide. The salt water is comparatively low in organic matter, and contains a plentiful supply of free oxygen. A large portion of the drainage that passes into the basin passes out on the ebb, and the portion which enters it again on the returning tide has been thoroughly mixed with the oxygen-bearing sea water. As the amount of organic matter in the salt water entering each day does not change materially, it is fair to assume that the pollutions entering are efficiently cared for by sedimentation, dilution and oxidation, even though a considerable proportion of the harbor water entering on one tide returns upon the next, and so on, thus making the complete change of the body of salt water a matter of days.

During a large portion of the year, and particularly in the spring months, the water flowing over Watertown dam undoubtedly contains as much or more free oxygen than the sea water, and not much, if any, more organic matter. During a dry summer, however, this entering fresh water contains less free oxygen than the harbor water, and considerably more organic matter. One of the chief questions, then, in the study of this problem, is, if the dam is erected, will the proposed fresh-water basin, containing in the spring 3,300,000,000 gallons of water practically saturated with free oxygen, be robbed of this oxygen by the organic matter in the street wash drainage and sewage overflow entering during the summer? Assuming what is undoubtedly true, that it is certain there will be a plentiful supply of oxygen in the water during the colder nine months of the year, will the organic matter in the water of the proposed Charles basin and in the entering upland water, together with that from the street wash and sewage overflows, become

oxidized by the work of aerobic bacteria during warm weather at the expense of the free oxygen, but without the exhaustion of this oxygen and hence without the production of odors; or will the oxygen be insufficient, and putrefaction and the production of odors from anaerobic bacterial action ensue? In this connection, it must be remembered that, besides the oxygen present in the waters of the basin at the beginning of warm weather, the water entering daily will contain more or less, and much will be absorbed from the air by the surface water. In this last connection it must be understood that, under any circumstances which can exist in the basin, the surface water will be continually changing; the basin lies so that it is exposed to the unrestricted sweep of the prevailing summer wind, and even at times of a light breeze the change will be quite rapid, and hence each day there is a chance for much oxygen to be taken up by the water of the basin in this way.

In order to satisfactorily answer the questions, however, not only the character of the water filling the basin in the spring must be known, but also the character of the water and drainage entering through the summer, and something must also be known in regard to the volume of the drainage. Such knowledge of the water and drainage has been gained by the analytical work given in the tables on previous pages, and the volume of water and drainage from different sources has been determined by you. To study this question more thoroughly, however, than can be done with this data only, some comparisons are necessary to show the amount of pollution with which water can be loaded and still retain oxygen.

The proposed basin would contain about 3,300,000,000 gallons, and 1 per cent. of this volume would be 33,000,000 gallons; that is, if so large a volume of sewage as 33,000,000 gallons entered the basin, it would be only 1 per cent. of the volume of water in the basin. Nothing approximating this volume of sewage enters the basin for any long period; but we may assume, for present purposes of discussion, that a volume of water or drainage containing organic matter equal to that in 1,000,000 gallons of average sewage (equivalent to all that from 13,333 persons at 75 gallons per capita) may now enter the basin below Watertown dam daily, or $\frac{1}{33}$ of 1 per cent. of the total volume of water in the basin. On days of storm, when sewer overflows are discharging, a volume of liquid containing several times this amount of organic matter may perhaps enter. The question, then, in regard to the sanitary condition of the proposed basin, is, in the first place, whether or no there will ever be a time, under any conditions which are likely to exist, when the large volume of fairly pure water in the basin at the beginning of the summer season containing much dissolved oxygen, will fail to dilute and oxidize sufficiently the drainage or sewage entering.

A Study of the Pollution of Water without the Exhaustion of Oxygen.

Many illustrations of the pollution of streams within the borders of the State and the dissipation of this pollution by dilution, sedimentation and oxidation might be cited. This I have not undertaken to do here, however, although the subject will be mentioned further in this report, but I have made instead certain experiments, the results of which are of significance as bearing on this point.

The water flowing in the river above Watertown dam has during almost the entire year an abundance of oxygen. This we may be sure of, not only from our own analyses, but also from the long continued

examinations of the State Board of Health. Even during dry summer weather, when but little waste water is flowing over the dam, it contains a considerable percentage of dissolved oxygen. Portions of the ten samples collected on September 22, of water flowing over the dam or through the raceways, all of which contained free oxygen, although the river was low, were incubated at 80° F. for five days; that is, they were placed in tightly stoppered bottles and maintained at this temperature, the bottles being filled and air excluded. Although the volume of oxygen present at the beginning of the experiment was not over 30 per cent. of saturation in any case, and in several instances less, in only four of the samples was it exhausted by the bacterial changes of the organic matter during the period of incubation; that is, in only four of them was there enough organic matter, or organic matter of an easily oxidized nature, present to exhaust the oxygen under this severe test. These experiments were repeated with other samples, and with similar results.

In almost all the further experimental work now presented the aim has been to show how large a volume of sewage could be mixed with water under different conditions and for different lengths of time, without exhausting the oxygen primarily present in the water, and hence without producing odors from putrefaction; but with no idea of asserting that such proportions of sewage are allowable in a body of still or slowly moving water, as some of the experiments, unless properly understood, might indicate. In the first experiments, certain percentages of sewage were mixed with both fresh and salt water, and the mixtures incubated in tightly stoppered bottles at a temperature of 80° F. for five days, with results similar to the following: —

Incubation of Fresh Water and Sea Water containing Various Percentages of Sewage.

	Dissolved Oxygen, Per Cent. of Saturation.	
	Fresh Water.	Salt Water.
At beginning of experiment,	96.0	88.5
After five days: —		
1 per cent. by volume of sewage in water,	71.0	28.3
3 per cent. by volume of sewage in water,	61.5	19.1
5 per cent. by volume of sewage in water,	25.1	0.6
10 per cent. by volume of sewage in water,	0.0	0.0

A number of comparative experiments along this line were also made; that is, a comparison of the results of incubation when air was excluded from the surface of the water in the bottles, with air results, as follows: Two sets of dissolved oxygen bottles, containing fresh water with 1, 3, 5 and 10 per cent. of sewage respectively, were prepared; one set of bottles was kept stoppered and in the incubator at 80° F. for five days, while the duplicate set was kept unstoppered in the laboratory for five days. The amount of dissolved oxygen remaining at the end of the five days was determined in both sets. The water at the beginning of the experiment contained 88.7 per cent. of saturation of dissolved oxygen.

Incubation of Water containing Various Percentages of Sewage.

	Stoppered, at 80° F.		Unstoppered, at 70° F.	
	Dissolved Oxygen, Per Cent. of Saturation.	Odor.	Dissolved Oxygen, Per Cent. of Saturation.	Odor.
1 per cent. of sewage, .	84.9	V. slight.	78.3	Not noticeable.
3 per cent. of sewage, .	45.3	Slight, sewage.	65.9	Not noticeable.
5 per cent. of sewage, .	0.0	Slight, sewage.	32.5	Not noticeable.
10 per cent. of sewage, .	0.0	Decided, sewage.	2.7	Slightly musty.

Other tests of this nature with both fresh and salt water were carried on with similar results, and with several of these complete analyses were made, as follows: Two half-gallon bottles were filled, one with equal parts of sea-water and sewage and the other with equal parts of fresh water and sewage. The bottles were kept open on the laboratory table at an average temperature of 70° F., and were examined at the end of four days. A duplicate set was also prepared, which were kept stoppered in the incubator. At the end of four days the appearance and odor were noted and analyses made.

Analyses.

[Parts per 100,000.]

	Color.	Odor.	Ammonia.			Chlorine.	Nitrogen as		Oxygen Consumed.
			Free.	Albuminoid. Total.	Albuminoid. In Solution.		Nitrates.	Nitrites.	
At start: —									
Sewage, ...	–	–	4.70	.38	.1600	15.80	–	–	2.04
Sewage and fresh water,	.53	Decided, sewage.	2.10	.16	.0920	8.09	.021	.0025	1.18
Sewage and salt water, .	.28	Decided, sewage.	2.50	.16	.0560	750.00	.004	.0016	1.86
After four days: —									
Sewage and fresh water, open, ...	.58	Decided.	2.35	.12	.0800	–	.005	.0000	1.18
Sewage and fresh water, closed, ...	.55	Offensive.	2.35	.12	.0800	–	.005	.0000	1.18
Sewage and salt water, open, ...	.40	Decided.	2.35	.12	.0760	–	.005	.0000	1.76
Sewage and salt water, closed, ...	.40	Offensive.	2.35	.12	.0760	–	.003	.0000	1.90

Practically identical results were obtained in each case, as the table shows, with the exception that both mixtures which were incubated had an offensive odor at the end of the period of incubation, and the oxygen in these bottles had become exhausted.

Many other similar experiments were made, by which mixtures of fresh water and sewage and salt water and sewage were compared. Almost invariably there was a more decided odor produced at first in

the fresh-water mixture, this becoming generally less after a certain period; while the odors in the mixtures of salt water and sewage, slight at first, increased in intensity.

Salt Water holds Less Oxygen in Solution than Fresh Water.

I have found in the course of this investigation that, temperatures and other conditions being equal, salt water apparently holds less oxygen in solution than fresh water. Its capacity in this respect decreases, moreover, when it is concentrated by evaporation and its density increased, while concentration is practically without effect upon the capacity of fresh water for the absorption of oxygen. This being so, it is evident that, volume for volume, fresh water can receive the greater amount of pollution without the exhaustion of its oxygen, if bacterial life is of equal vigor in each case.

Tank Experiments upon the Pollution of Water and the Consumption of Oxygen.

To make further studies upon the volume of sewage that can be cared for by a given volume of water without the exhaustion of its dissolved oxygen, several large experimental tanks were put into operation, and these were intended to be so operated as to compare still with moving water. These tanks were each 12 feet deep and 20 inches in diameter, the surface water and the upper two or three feet of each tank being exposed to the sunlight, while the lower portion was in a building, and hence shaded; that is, the tanks projected through the roof of one of the sheds at the Lawrence Experiment Station. Practically, however, all the water introduced into the tanks, through which there was a slight current, was for a number of days under conditions resembling the bottom layers of still water; that is, the water was passed in near the bottom of the tank, and rose slowly to the surface. One tank contained 12 feet in depth of water, to which 4½ per cent. by volume of average sewage was added. This experiment was continued for four weeks. The surface of the water was exposed to the air and sunlight, and temperature readings were taken frequently of the air, surface water and water at various depths in the tank. During more than half the time covered by the experiment the temperature in the direct sunlight over the tank reached a maximum each day of more than 75° F., upon ten days a maximum greater than 80° F., and upon four days a maximum greater than 90° F. Daily examinations for dissolved oxygen were made upon samples of surface water and upon water from depths of 4 and 8 feet. Complete chemical analyses of samples were made every third day. The average amount of free and albuminoid ammonia in the water was about .2000 and .0450 parts per 100,000 respectively. The results of the many tests of this water made during the course of the experiment showed that, while the dissolved oxygen disappeared in four days, it was present again upon the eighth day and until the end of the experiment. The water was always of good appearance, and its odor was very slight; no sewage odor could be detected. Although the oxygen was exhausted in four days, I believe that this was caused by the condition of the tank when put into use rather than by the sewage introduced, as further experiments showed different results.

A second tank of the same size was put into operation, through which water, containing at first 4½ per cent. of sewage and later 7 per cent., was passed at such a rate that it was at first seven days in passing through the tank and later ten days; that is, the water was passed in

near the bottom of the tank and rose slowly towards the top, where it overflowed. The same tests and analyses were made as with the water from the first tank. The chemical analyses and observations showed that much of the organic matter introduced with the sewage settled; and this is, of course, what might be expected, and would occur in a still basin. This experimental tank was continued in operation for two weeks; dissolved oxygen was always found in the water at all depths, and the water was practically odorless.

At the end of two weeks, or upon September 17, owing to the starting upon September 8 of a third experimental tank containing water of the same character as that in this tank and operated in the same way, but containing also mud from the Charles River, Tank No. 2 was emptied, refilled with water containing 4½ per cent. by volume of sewage, and then allowed to stand without change of water until the end of October. Throughout this period of more than six weeks the water was of good appearance, practically odorless, and contained dissolved oxygen. The tables of analyses follow. Dissolved oxygen determinations were made daily, but only those made on the days of complete analyses are given in the table.

Experimental Tank No. 2.— Second Period.

[Parts per 100,000.]

DATE. 1902.	Depth.	Color.	Ammonia.		Chlorine.	Nitrogen as		Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Bacteria per c. c.
			Free.	Albuminoid.		Nitrates.	Nitrites.			
Sept. 17, .	Average sample,	.36	.2940	.0340	.76	.033	.0000	.40	-	98,600
Sept. 20, .	Surface, . .	.40	.2250	.0300	.77	.024	.0070	.34	3.7	96,600
	4 feet, . . .	.41	.2230	.0270	.77	.025	.0070	.36	3.0	81,000
	8 feet, . . .	.41	.2170	.0310	.77	.018	.0080	.37	1.9	132,500
Sept. 23, .	Surface, . .	.39	.2180	.0170	.77	.003	.0160	.32	5.2	60,600
	4 feet, . . .	.39	.2050	.0200	.77	.008	.0160	.30	4.1	16,400
	8 feet, . . .	.38	.2190	.0140	.77	.003	.0160	.30	4.9	16,000
Sept. 26, .	Surface, . .	.38	.2290	.0210	.77	.000	.0160	.32	10.1	17,300
	4 feet, . . .	.38	.2330	.0260	.77	.000	.0160	.32	9.3	14,400
	8 feet, . . .	.37	.2250	.0190	.77	.000	.0140	.32	8.7	16,700
Sept. 29, .	Surface, . .	.36	.2210	.0210	.77	.000	.0140	.33	18.1	23,300
	4 feet, . . .	.36	.2190	.0200	.77	.000	.0140	.32	16.7	41,200
	8 feet, . . .	.36	.2220	.0200	.77	.001	.0140	.30	16.3	32,200
Oct. 2, .	Surface, . .	.34	.2110	.0190	.77	.000	.0120	.30	16.0	7,300
	4 feet, . . .	.36	.2130	.0160	.77	.000	.0120	.30	10.3	38,600
	8 feet, . . .	.36	.2140	.0180	.77	.001	.0120	.30	10.4	38,600
Oct. 5, .	Surface, . .	.35	.2140	.0200	.76	.000	.0110	.29	28.3	5,500
	4 feet, . . .	.35	.2100	.0160	.77	.000	.0110	.28	21.7	3,900
	8 feet, . . .	.35	.2100	.0170	.77	.000	.0100	.28	22.2	3,000
Oct. 8, .	Surface, . .	.38	.2210	.0270	.76	.000	.0110	.29	32.4	6,100
	4 feet, . . .	.38	.2320	.0190	.77	.000	.0110	.27	28.2	2,100
	8 feet, . . .	.36	.2250	.0190	.77	.000	.0110	.26	29.1	2,600
Oct. 15, .	Surface, . .	.43	.2010	.0260	.74	.000	.0100	.25	40.4	1,800
	4 feet, . . .	.35	.2120	.0270	.77	.000	.0100	.25	29.4	1,800
	8 feet, . . .	.35	.2050	.0290	.77	.000	.0100	.24	28.6	2,200
Oct. 22, .	Surface, . .	.33	.2220	.0200	.75	.003	.0080	.28	37.0	4,700
	4 feet, . . .	.33	.2130	.0190	.77	.003	.0080	.26	31.3	2,000
	8 feet, . . .	.33	.2240	.0190	.77	.003	.0080	.23	29.5	11,400

Tank No. 2.— Temperature at Noon Each Day (Degrees F.).

Day of Month. 1902.	September.				October.			
	At Top of Tank (in Sunlight).	Surface Water.	Depth. Four Feet.	Depth. Eight Feet.	At Top of Tank (in Sunlight).	Surface Water.	Depth. Four Feet.	Depth. Eight Feet.
1, . .	-	-	-	-	60	61	61	61
2, . .	-	-	-	-	79	67	65	62
3, . .	-	-	-	-	77	70	64	62
4, . .	-	-	-	-	81	69	62	59
5, . .	-	-	-	-	58	58	58	57
6, . .	91	72	65	63	76	68	65	64
7, . .	71	64	64	62	82	69	61	59
8, . .	97	78	70	66	-	62	60	57
9, . .	87	75	68	67	76	60	56	55
10, . .	86	73	67	64	76	55	53	49
11, . .	91	79	66	63	63	52	52	48
12, . .	92	76	67	65	57	57	56	54
13, . .	64	65	64	64	85	59	57	53
14, . .	76	73	63	60	76	64	62	59
15, . .	90	72	62	58	69	58	55	53
16, . .	84	71	61	58	72	56	55	53
17,* . .	65	60	58	57	70	54	52	50
18, . .	63	62	61	60	47	44	45	44
19, . .	65	63	62	62	83	67	62	55
20, . .	67	64	63	63	61	67	63	60
21, . .	65	64	61	60	53	53	58	52
22, . .	70	67	62	61	63	54	51	45
23, . .	107	75	67	63	57	50	48	47
24, . .	71	73	67	64	59	55	44	45
25, . .	67	61	58	57	68	64	57	53
26, . .	62	59	58	57	55	51	45	44
27, . .	60	60	59	58	-	-	-	-
28, . .	70	65	63	61	-	-	-	-
29, . .	63	65	63	63	-	-	-	-
30, . .	63	63	63	63	-	-	-	-

* Temperature taken at 8.30 A.M.

Tank No. 3, Carboy and Gallon Bottle Experiments.

A wooden tank, containing about 225 gallons of water, had 3 per cent. by volume of sewage added on the first day of operation, or 6.75 gallons, and 3 per cent. daily thereafter. The dissolved oxygen was thirteen days in disappearing. That is, to the 225 gallons of Merrimack River water primarily in the tank, 87.7 gallons of sewage were added slowly, before the oxygen present was exhausted. The temperature of the water was about 68° F. during the time of the experiment. This experiment was vitiated somewhat by the new wooden tank in which it was carried on, which had been creosoted, this helping to use up the oxygen.

A similar experiment upon a smaller scale was made in a five-gallon carboy partially filled, with blackened sides, but with the surface water exposed to the light and air, and with the water maintained at laboratory temperature. In this experiment 3 per cent. of sewage was added at the start and 3 per cent. daily thereafter. The dissolved oxygen was nineteen days in becoming exhausted, but was found thereafter, showing a certain amount absorbed each day. Each day 3 per cent. of the liquid was withdrawn for purposes of analysis at the time 3 per cent. of sewage was added, so that at the end of thirty days 51 per cent. of the liquid in the bottle was the added sewage. An incubator experiment, a duplicate of this last, with the temperature maintained at approximately 80° F., was also made. The results are shown in the following tables; and it must be remembered that in these experiments strong sewage not containing any free oxygen was passed into bodies of water at first

saturated with oxygen, thus differing from the experiments with tanks Nos. 1 and 2, as into these tanks weak sewage was passed, containing when entering some dissolved oxygen.

Carboy Experiment.—Dissolved Oxygen Determinations.

1902.	Temperature (Degrees F.).	Dissolved Oxygen, Per Cent. Saturation.	1902.	Temperature (Degrees F.).	Dissolved Oxygen, Per Cent. Saturation.
Oct. 9,	63	90.4	Oct. 25,	77	2.6
10,	90	88.9	26,	76	14.1
11,	63	66.2	27,	65	14.2
12,	62	55.6	28,	66	0.0
13,	75	56.9	29,	63	0.7
14,	92	58.2	30,	77	2.3
15,	84	59.6	31,	77	0.6
16,	81	60.1	Nov. 1,	78	0.0
17,	85	43.7	2,	84	4.6
18,	56	36.1	3,	81	6.2
19,	71	25.6	4,	87	2.5
20,	91	37.0	5,	77	4.6
21,	67	43.1	6,	70	7.4
22,	76	38.4	7,	73	3.8
23,	65	16.7	8,	67	0.0
24,	75	21.5			

Gallon Bottle Experiment (Incubation at 80° F.).—Dissolved Oxygen Determinations.

Oct. 9,	62	93.6*	Oct. 25,	80	28.7
10,	83	82.0	26,	80	28.7
11,	81	64.0	27,	79	35.5
12,	78	57.4	28,	79	19.9
13,	80	53.1	29,	78	33.6
14,	80	58.9	30,	83	26.8
15,	80	70.3	31,	91	11.5
16,	77	72.9	Nov. 1,	88	22.0
17,	83	55.2	2,	83	31.3
18,	86	44.4	3,	83	4.5
19,	81	42.2	4,	89	30.3
20,	81	43.6	5,	86	13.5
21,	81	62.5	6,	83	20.9
22,	81	42.2	7,	80	13.0
23,	80	24.4	8,	81	0.0
24,	80	28.7			

* Tap water used.

The per cent. of sewage at the end of thirty days was the same as that in the carboy experiment, namely, 50.8. The bottle was unstoppered.

Still and Dripping Water Experiments.

Further experiments along this line were made as follows, these last being laboratory tests to show the difference in the volume of dissolved oxygen retained in a body of water when sewage is being added daily and the surface of the water only is exposed to the air (still water), and when sewage is being added daily but every drop of water in a given volume is passing through the air twice in twenty-four hours, and thus becoming saturated with oxygen. In order to make this comparison, two one-gallon bottles were nearly filled with tap water saturated with oxygen, the liquid in one bottle remaining quiet, while in the other a siphon was so arranged that this liquid dripped constantly through the

air on to a funnel, over and through which it ran into a second bottle. All the bottles were open and air admitted. At first 3 per cent. of sewage was added daily to the liquid of each experimental bottle. On the seventh day, owing to the maintenance of much oxygen in the dripping experiment, the volume of sewage added was increased to 6 per cent., upon the fourteenth day to 12 per cent., and upon the twenty-first day to 18 per cent. The volume added daily to the still water was not increased, as the free oxygen disappeared steadily. The comparative results follow.

Still Water Experiment.— Dissolved Oxygen Determinations.

DATE. 1902.	Temperature (Degrees F.).	Dissolved Oxygen, Per Cent. Saturation.	
Oct. 26, . . .	61	88.1	Tap water at start.
27, . . .	66	92.8	Three per cent. of sewage added daily.
28, . . .	67	53.8	
29, . . .	63	39.6	
30, . . .	65	34.2	
31, . . .	68	30.4	
Nov. 1, . . .	63	30.0	
2, . . .	60	23.3	
3, . . .	67	21.3	
4, . . .	70	7.7	
5, . . .	70	7.7	
6, . . .	70	2.6	
7, . . .	69	3.8	
8, . . .	57	10.1	
9, . . .	61	4.5	
10, . . .	66	11.1	
11, . . .	64	6.1	
12, . . .	67	3.8	
13, . . .	61	3.5	
14, . . .	70	0.0	
15, . . .	65	4.9	
16, . . .	65	0.0	On November 16 the mixture contained 45 per cent. of sewage.

Dripping Experiment.— Dissolved Oxygen Determinations.

Oct. 26, . . .	66	100.0	Tap water at start.
27, . . .	68	100.0	Three per cent. of sewage added daily.
28, . . .	67	94.1	
29, . . .	63	97.1	
30, . . .	65	97.4	
31, . . .	68	87.9	
Nov. 1, . . .	63	87.6	Six per cent. of sewage added daily.
2, . . .	61	79.9	
3, . . .	68	84.1	
4, . . .	70	72.2	
5, . . .	70	56.5	
6, . . .	71	54.3	
7, . . .	70	57.4	
8, . . .	55	66.0	Twelve per cent. of sewage added daily.
8, . . .	58	52.1	
9, . . .	61	68.3	
10, . . .	68	43.2	
11, . . .	65	25.2	
12, . . .	69	19.6	
13, . . .	61	49.2	
14, . . .	71	34.5	
15, . . .	65	34.6	
16, . . .	65	30.8	

As a volume of the mixed liquid equal to the volume of sewage added daily was taken for each determination, on November 15 the liquid in the bottle contained 82 per cent. of sewage.

Purification in Still and Running Water.

A further experiment along this line was as follows: A mixture of 80 per cent. tap water and 20 per cent. sewage was allowed to stand quiescent with its surface exposed to the air, and a similar mixture was continually passed through the air, as in the dripping experiment just described. Frequent examinations were made to determine the oxidation occurring in each, and the earliest nitrification occurred in the still water; that is, the continual introduction of air in the dripping experiment did not hasten purification by bacterial action.

Resumé.

In all of this experimental work upon dissolved oxygen the mixtures of water and sewage have purposely been made to contain vastly greater volumes of sewage than under any circumstances could occur in the basin, if constructed, to illustrate: (1) the practical maintenance of a state of equilibrium if water containing considerable sewage, but also containing dissolved oxygen, remains in or slowly passes through a basin; (2) the fact that water containing as much nitrogen in a state of change as the water in Tank No. 2 (first and second periods) retains much dissolved oxygen and does not give off odors; (3) the volume of sewage that can be added to water without the exhaustion of oxygen, if the addition is gradual; (4) that purification by bacterial action occurs as readily in still as in moving water if oxygen is present.

Deposits of Mud in the River and in the Fenways.

Another question of importance enters into the discussion of the character of the water in the basin and the production of odors if this basin is constructed, and that is the part which the present deposits of mud at places would play in robbing the comparatively still water in the summer season of free oxygen, putrefying and giving off offensive gases. The mud flats of the entire estuary from Watertown dam to Craigie bridge have been noted, and samples for inspection and analysis collected, especially from the most offensive deposits. Mud flats are noticeable at low tide from the dam to Watertown Arsenal, but these banks are in general free from much organic matter. From this point to a mile or so above Harvard bridge the banks of the river are generally steep and show little that is offensive, with one or two notable exceptions. There is a very offensive bank of putrefying sludge and mud just above the Brighton Abattoir, due apparently to drainage from a starch factory. In the lower basin there are offensive mud flats of a limited area; that is, offensive at low tide, when odors from the decaying organic matters are given off. Fourteen samples from the various deposits have been collected for analysis and experiment. The percentage of nitrogen present in these samples has been determined, as nitrogenous bodies decay most easily, and also the loss in weight which they sustain when heated to a high temperature; that is, when all the organic matter, both carbonaceous and nitrogenous, is consumed, this giving the total organic matter present. These results are shown in the following table, in comparison with similar average results with ordinary dried sewage sludge and black and brown loam. It will be noticed that the most offensive mud contained only about one-ninth as much nitrogen as sewage sludge, and that it lost only one-

third as much by weight upon ignition. Five of the remaining samples contained more organic matter than black loam, and this matter was of a less stable character.

Percentage of Nitrogen and Amount of Organic Matter in Charles River Mud, Sewage Sludge and Brown and Black Loams.

	Per Cent. of Nitrogen (by Weight).	Loss on Ignition (Per Cent. by Weight).
Mud No. 1,	0.230	3.02
Mud No. 3,	0.055	3.73
Mud No. 4,	0.180	8.02
Mud No. 5,	0.400	21.75
Mud No. 6,	0.020	1.92
Mud No. 8,	0.040	2.17
Mud No. 11,	0.240	11.52
Mud No. 12,	0.140	6.49
Mud No. 13,	0.297	13.17
Mud No. 14,	0.232	14.78
Mud No. 15,*	–	–
Mud No. 16,	0.302	11.97
Mud No. 17,	0.269	13.03
Mud No. 18,	0.160	6.70
Sewage sludge,	3.520	66.70
Brown loam,	0.440	3.80
Black loam,	0.510	10.60

* Contained coal, which caused misleading results.

Tank Experiment with Polluted Water and Mud.

Tank No. 4.

Nine inches in depth of the most offensive of these muds, that is, the one containing the greatest amount of organic matter, was placed in the bottom of a tank 12 feet deep, and water containing at first 5 per cent. by volume of sewage, and a day or two later 7 per cent., was passed through the tank; that is, the theoretical composition of the liquid applied daily was such that it contained .1000 parts of free ammonia and .0600 parts of albuminoid ammonia per 100,000. It really averaged higher in albuminoid ammonia, and the analyses in the table marked "surface water," September 28 and following, are of the water introduced. Everything in the operation of this experiment and the period covered by it was the same as in the similar experiment described on page 273, with the exception of the introduction of mud. The results were practically identical with this first experiment, dissolved oxygen always being present in the water of this tank at all depths, and the odor of the water being slight. Some anaerobic action occurred in the mud, however, and occasional bubbles of gas rose to the surface. The following table gives the chemical analyses of samples taken from different depths, together with dissolved oxygen determinations on the day of complete analysis. This tank stood beside Tank No. 2, mentioned on page 273, and the temperature readings were practically identical.

Experimental Tank No. 4.

[Parts per 100,000.]

DATE. 1902.	Depth.	Color.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Nitrogen as Nitrates.	Nitrogen as Nitrites.	Oxygen Consumed.	Dissolved Oxygen, Per Cent. Saturation.	Bacteria per c. c.
Sept. 8,	Sewage,	–	4.5000	.3800	14.60	–	–	2.44	–	–
	Average sample,	.41	0.1000	.0290	1.43	.032	.0000	0.50	–	12,100
11,	Surface,	.39	0.1660	.0260	1.49	.031	.0010	0.37	38.5	109,300
	4 feet,	.39	0.1510	.0230	1.56	.031	.0010	0.37	36.1	198,700
	8 feet,	.39	0.1520	.0210	1.56	.030	.0010	0.37	34.6	192,400
14,	Surface,	.41	0.2220	.0520	1.65	.029	.0014	0.35	28.6	124,600
	4 feet,	.40	0.2080	.0280	1.62	.029	.0014	0.34	27.0	172,500
	8 feet,	.40	0.2220	.0250	1.62	.029	.0014	0.34	26.7	208,700
16,	Average sample,	.45	0.1210	.0580	0.97	.033	.0006	0.68	–	70,500
19,	Surface,	.45	0.1190	.0310	0.88	.029	.0040	0.39	13.1	623,000
	4 feet,	.46	0.1160	.0340	0.88	.030	.0050	0.37	9.1	623,000
	8 feet,	.45	0.1080	.0290	1.18	.029	.0040	0.38	19.2	504,000
22,	Surface,	.38	0.1310	.0330	0.81	.014	.0070	0.34	13.5	120,500
	4 feet,	.39	0.1190	.0310	0.81	.017	.0070	0.33	10.5	112,000
	8 feet,	.38	0.1180	.0240	0.87	.014	.0090	0.32	1.6	100,000
25,	Surface,	.41	0.1200	.0300	0.74	.009	.0080	0.31	9.7	40,500
	4 feet,	.41	0.1180	.0280	0.82	.008	.0090	0.31	9.7	35,500
	8 feet,	.40	0.1330	.0250	0.85	.010	.0080	0.31	9.5	60,000
28,	Surface,	.27	0.1030	.0900	0.40	.034	.0000	0.64	15.5	32,000
	4 feet,	.31	0.1120	.0310	0.68	.013	.0040	0.37	13.2	34,000
	8 feet,	.34	0.1210	.0250	0.80	.009	.0060	0.33	2.8	53,000
Oct. 1,	Surface,	.35	0.0980	.0720	0.62	.000	.0000	0.53	7.9	67,000
	4 feet,	.34	0.1100	.0210	0.82	.011	.0055	0.32	8.5	73,000
	8 feet,	.32	0.1180	.0180	0.74	.011	.0055	0.30	8.1	105,000
4,	Surface,	.33	0.1020	.0660	0.57	.034	.0000	0.53	19.4	97,000
	4 feet,	.34	0.1100	.0200	0.76	.016	.0050	0.32	13.8	187,000
	8 feet,	.36	0.0920	.0180	0.84	.007	.0055	0.30	22.2	83,000
7,	Surface,	.38	0.1010	.0810	0.45	.034	.0000	0.63	15.0	50,600
	4 feet,	.38	0.1140	.0260	0.70	.015	.0040	0.30	14.1	82,000
	8 feet,	.36	0.1130	.0270	0.73	.015	.0040	0.30	12.7	36,600
14,	Surface,	.32	0.0520	.0590	0.46	.032	.0002	0.55	31.7	174,000
	4 feet,	.30	0.0820	.0340	0.59	.018	.0030	0.30	12.9	76,000
	8 feet,	.30	0.0820	.0220	0.69	.016	.0030	0.31	12.8	166,000
21,	Surface,	.35	0.0440	.1810	0.38	.013	.0000	1.00	26.3	203,000
	4 feet,	.31	0.0750	.0250	0.63	.029	.0022	0.31	21.3	189,000
	8 feet,	.31	0.0750	.0220	0.63	.021	.0022	0.31	20.1	163,000

INCUBATION OF SAMPLES OF MUD, ETC., IN FRESH AND SALT WATER.

In order to test the rapidity of the exhaustion of oxygen by bacterial life in these muds under fresh and salt water conditions, certain experiments were made, as follows: Portions of the samples of mud were incubated in water containing dissolved oxygen, both fresh and salt water being used. Two grams of each of the muds were placed in half-gallon bottles. Into one set of these bottles fresh water was introduced, and into a second set sea water. The bottles were then stoppered, and kept at 80° F. for five days. After this period, portions were siphoned off

for dissolved oxygen determinations. The appearance of the supernatant liquid, and the odors, were also noted. At the beginning of these tests the fresh water was saturated with oxygen, and the salt water contained 88.4 per cent. of saturation. The results follow: —

	Dissolved Oxygen in the Water.			
	Per cent. of Saturation after five Days.		Per cent. of Oxygen at start remaining after five Days.	
	Fresh.	Salt.	Fresh.	Salt.
Mud No. 1,	51.3	32.1	51.3	41.8
Mud No. 3,	79.9	37.0	79.9	41.8
Mud No. 4,	58.9	18.9	58.9	21.4
Mud No. 5,	33.0	0.0	33.0	0.0
Mud No. 6,	60.5	28.6	60.5	32.3
Mud No. 8,	81.2	31.7	81.2	35.9
Mud No. 11,	53.0	19.1	53.0	21.6
Mud No. 12,	61.4	13.7	61.4	15.5
Mud No. 13,	67.2	11.3	67.2	12.9

It will be noticed that in every instance the incubation in sea water exhausted more oxygen than the incubation in fresh water. As the amount of oxygen was greater in the fresh water at the start than in the sea water, columns are given showing the percentage in each case which the oxygen remaining was of the amount primarily present. In only one instance was the oxygen exhausted. *One-tenth as much by weight of dried sewage sludge as of the muds used in these experiments exhausts oxygen under similar conditions, as proved by many tests.*

A period of reincubation was then tried. To the water remaining in the bottles from the first experiments started on September 21 and September 25 was added in each case one gram more of the respective materials. The bottles were then filled to the stopper with fresh water and sea water respectively, the water aerated, and the bottles then stoppered and again placed in the incubator at 80° F. After ten days determinations were made of dissolved oxygen, and the results were as follows: —

	Dissolved Oxygen after Ten Days, per Cent. of Saturation.	
	Fresh.	Salt.
Mud No. 1,	78.1	67.8
Mud No. 3,	81.4	54.1
Mud No. 4,	63.3	28.2
Mud No. 5,	1.7	0.0
Mud No. 6,	92.8	67.5
Mud No. 8,	86.6	60.8
Mud No. 11,	27.8	19.3
Mud No. 12,	58.3	36.3
Mud No. 13,	56.9	24.7

Odors.

The odors were noted after the first and second incubations, and the most decided were from the incubation in salt water.

Bacterial Work.

Although this is not a question of water supply, and hence the number of bacteria present in the water of the basin is of little consequence compared with the amount of organic matter, yet considerable bacterial work has been done to give additional information upon the quality of the water entering the basin. Experimental work along this line has also been done, in an effort to throw as much light as possible upon what may occur in the basin if it is changed from a salt water to a fresh or brackish water basin.

Bacteria in River Samples.

Upon September 22 a number of samples of the water near to or flowing over Watertown dam were collected at different hours, and the results follow. On this day the flow of the river was low, and during only a portion of the day was water passing over the dam.

Sample Number.	Bacteria per c. c.	Sample Number.	Bacteria per c. c.
1,	9,700	4,	4,300
2,	2,300	5,	13,500
3,	10,600		

Mention has already been made of the series of bacterial samples collected, upon October 15 and 16, from the river at different points and depths from Newton Upper Falls nearly to Watertown dam, and the results of the examinations are here given: —

Station Number.	Bacteria per c. c.	Depth.	Station Number.	Bacteria per c. c.	Depth.
1,*	1,900	Surface.	5,	388	7 feet.
1,	2,400	2 feet.	6,	4,600	Surface.
2,	1,300	Surface.	7,	4,700	Surface.
2,	6,400	4 feet.	8,	5,700	Surface.
3,	2,100	Surface.	9,	14,200	Surface.
3,	8,400	6 feet.	9,	15,200	4 feet.
4,	356	Surface.	10,	16,600	Surface.
4,	956	15 feet.	10,	22,000	2 feet.
5,	1,300	Surface.	11,†	18,900	Surface.

* Newton Upper Falls. † A short distance above Watertown dam.

Upon October 17 a series of samples of the water flowing over Watertown dam from 7.45 A.M. to 4.45 P.M. was collected and examined, with the following results: —

Time.	Bacteria per c. c.	Time.	Bacteria per c. c.
7.45 A.M.,	2,900	12.45 P.M.,	6,300
8.45 A.M.,	3,300	1.45 P.M.,	9,300
9.45 A.M.,	3,100	2.45 P.M.,	5,100
10.45 A.M.,	2,700	3.45 P.M.,	2,400
11.45 A.M.,	4,400	4.45 P.M.,	1,900

Upon September 4 samples were collected from various points in the river below Watertown, and examined, with the following results: —

Sept. 4, 1902. High Tide at 12.41 P.M. Samples collected on Outgoing Tide.

No.	Place of Collection.	Bacteria per c. c.
1	Upper Western Avenue bridge, surface,	1,300
2	Upper Western Avenue bridge, 6 feet,	100
3	North Harvard Street bridge, surface,	600
4	North Harvard Street bridge, 11 feet,	500
5	Cottage Farm bridge, surface,	200
6	Cottage Farm bridge, 6 feet,	900
7	Harvard bridge, third pier from south end, surface,	2,700
8	Harvard bridge, third pier from south end, 2½ feet,	1,100
9	Harvard bridge, middle, surface,	1,200
10	Harvard bridge, middle, 6 feet,	500
11	Harvard bridge, twentieth pier, surface,	300
12	Forty feet from outlet of Stony Brook, surface,	600

Upon September 10 and 13 samples from different portions of the Charles River basin, between West Boston bridge and a mile above Harvard bridge, were collected and examined, with the following results: —

Sept. 10, 1902. Low Tide at 11.16 A.M. Samples collected on the Early Flood Tide, from 11.35 A.M. to 12.45 P.M.

Number.	Bacteria per c. c.	Number.	Bacteria per c. c.
1,	1,000	6,	4,000
2,	3,000	7,	6,000
3,	1,000	8,	22,000
4,	3,000	9,	1,000
5,	2,000		

Sept. 13, 1902. Low Tide at 1.52 P.M. Samples collected on Late Flood and Early Ebb Tide.

1,	3,800	5,	24,800
2,	2,600	6,	32,600
3,	33,800		

Samples collected just before low tide, where the river was particularly dirty, upon September 16, were plated, with the following results: —

Low Tide at 4.12 P.M.

Location.	Time.	Bacteria per c. c.
Below Beechwood Avenue, surface,	3.10 P.M.	1,397,000
Below Beechwood Avenue, 2 feet,	3.10 P.M.	8,500
Below Beechwood Avenue, surface,	3.30 P.M.	62,400
At Abattoir, surface,	4.10 P.M.	210,000
At Upper Western Avenue bridge, surface,	4.20 P.M.	39,500
At Upper Western Avenue bridge, 2 feet,	4.20 P.M.	11,000

Upon October 6 surface samples collected at different points from Watertown dam to West Boston bridge gave the following results: —

High Tide at 2.24 P.M. Samples collected on Late Flood and Early Ebb Tides.

Location.	Time.	Bacteria per c. c.
Watertown dam,	1.00 P.M.	46,600
One-quarter mile below Watertown dam,	12.45 P.M.	71,000
Opposite Watertown Arsenal,	2.00 P.M.	17,600
Opposite Abattoir,	2.15 P.M.	3,700
Opposite lower end of Cambridge cemetery,	2.30 P.M.	2,500
North Harvard Street bridge,	2.45 P.M.	1,300
Lower Western Avenue bridge,	2.45 P.M.	1,100
Cottage Farm bridge,	3.00 P.M.	800
Harvard bridge, north end,	3.00 P.M.	900
Harvard bridge, south end,	3.15 P.M.	4,100
Half way between Harvard and West Boston bridges,	3.20 P.M.	900
West Boston bridge,	3.30 P.M.	2,900

Oct. 10, 1902. Low Tide at 11.28 A.M. Samples collected on Late Ebb and Early Flood Tide.

No.	Place of Collection.	Depth.	Bacteria per c. c.
1	Lower Western Avenue bridge,	Surface.	6,800
		1 foot.	3,900
		7 feet.	3,300
2	Cottage Farm bridge,	Surface.	7,200
		1 foot.	2,000
		11½ feet.	1,300
3	Just above Harvard bridge,	Surface.	7,500
		1 foot.	6,200
		9 feet.	1,800
4	Opposite Muddy River outlet,	Surface.	11,900
		Bottom.	4,800

Upon September 12 samples were collected for bacterial analysis from four different places in the Fens basins. Samples were collected from the surface and at a depth, and the bacterial results are here given, together with the chemical analyses: —

[Parts per 100,000.]

Location.	Ammonia.				Chlorine.	Dissolved Oxygen, Per Cent. Saturation.	Bacteria per c. c.
	Free.	Albuminoid.					
		Total.	In Solution.	In Suspension.			
At entrance of Stony Brook into the Fens, surface.	.1350	.0420	.0255	.0165	133.00	0.0	108,000
At entrance of Stony Brook into the Fens, 3 feet.	.2700	.0850	.0370	.0480	1290.00	0.0	4,500
First bridge below Huntington Avenue, surface.	.1350	.0415	.0225	.0190	144.00	0.0	181,000
First bridge below Huntington Avenue, 2 feet.	.0720	.0560	.0340	.0220	1285.00	0.0	1,500
Second bridge below Huntington Avenue, surface.	.1000	.0710	.0430	.0280	344.00	2.6	131,000
Second bridge below Huntington Avenue, 4 feet.	.3300	.0650	.0390	.0260	1365.00	0.0	2,500
Commonwealth Avenue bridge, surface.	.0520	.1015	.0610	.0405	565.00	74.0	23,500
Commonwealth Avenue bridge, 5½ feet.	.1200	.0470	.0290	.0180	1365.00	0.0	2,000

Upon November 8 samples from different locations in the Fens were again collected, and the bacterial results follow: —

No.	Location.	Bacteria per c. c.
1	Brookline Avenue, gate house, surface,	134,200
2	Brookline Avenue, gate house, 6 feet,	10,200
3	Between Brookline Avenue and first stone bridge, surface,	513,300
4	Between Brookline Avenue and first stone bridge, 6 feet,	10,300
5	Stone bridge below Brookline Avenue, surface,	105,100
6	Stone bridge below Brookline Avenue, 6 feet,	21,000
7	Opposite "Italian palace," surface,	321,600
8	Opposite "Italian palace," 5 feet,	20,300
9	Between "Italian palace" and Stony Brook, surface,	586,900
10	Between "Italian palace" and Stony Brook, 5 feet,	66,400
11	Muddy River, where it enters Stony Brook channel, surface,	285,800
12	Muddy River, where it enters Stony Brook channel, 2 feet,	95,600
13	Stony Brook channel, opposite where Muddy River enters, surface,	221,500
14	Stony Brook channel, above where Muddy River enters, surface,	389,800
15	Stony Brook channel, above where Muddy River enters, 4 feet,	16,500
16	Stony Brook channel, below Muddy River, surface,	218,200
17	Stony Brook channel, below Muddy River, 2 feet,	9,600
19	Beacon Street tide gates, surface,	12,400

Summary of Bacterial Results.

The average number of bacteria found in the main portion of the course of the Charles River above Watertown was considerably less than the average number in the Merrimack River water at Lawrence; the Merrimack River water being cited in this instance, as it is the one Massachusetts river which has had almost daily bacterial examination for the past twelve years. These samples from the Merrimack have been collected at Lawrence, which has taken its drinking water supply from the river since 1875, and until 1893 without filtration. All the bacterial samples from the tidal estuary were, unless otherwise stated, collected at or within a few inches of the surface. The results of examination indicate more or less pollution, thus confirming the chemical analyses. The degree of pollution upon each tide is shown more clearly by the chemical analyses, however, not only because more daily series for chemical analysis were taken, but also because the local pollutions of the estuary, flowing first this way and then that as the tide changes, interfere with the interpretation of the results of the examination of bacterial samples more than with the interpretation of the results of the examination of chemical samples. At places where samples were collected, not only at the surface but at various depths, the surface samples contained almost invariably the greater number of bacteria; these results confirming observations and chemical analyses, as showing that the surface water is more polluted than the lower water. The series of samples taken October 10 is particularly noticeable in this respect. Very few of the samples contained more than one five-hundredth as many bacteria as average sewage, and many of them not one-thousandth as many.

The degree of pollution of the water of the Fenways, as shown by the bacterial counts, agrees with the results of the chemical analyses. The average number of bacteria in Lawrence sewage during the years 1900–1901, as determined by almost daily analyses, was 2,500,000 per c. c. The highest number found in the most polluted water of the Fens was about one-fourth as great as this, and most of the surface samples contained only from one-hundredth to one-fifth as many as the Lawrence sewage. The samples collected at depths of from 2 to 6 feet showed much lower numbers of bacteria. This was due to the general

absence of oxygen in the brackish lower water, whereby aerobic forms were mainly killed, and perhaps many anaerobic forms did not develop on the plates in the laboratory, as these plates were developed with exposure to the air.

Experimental Bacterial Work.

Many questions seem to enter into the problem of changing the character of the water in the basin from fresh to salt, the answer to which can at least be indicated by bacterial investigations. One of these has already been spoken of, namely, the rapidity of the bacterial oxidation of organic matter in the mud under fresh and salt water conditions; and the results showed that in these experiments the quickest use of oxygen and the greatest production of odors occurred under salt-water conditions. In the Fens basin, through which a certain volume of salt water is supposed to pass daily, but which does not, I am afraid, always occur, as the lower and salt water layer is generally stagnant and devoid of oxygen, putrefaction with the production of sulphuretted hydrogen gas occurs. This is one of the most offensive gases which can be produced by putrefaction of organic matter, and its production seldom occurs to a noticeable extent under fresh-water conditions. In the modern septic tank used in sewage disposal, where sewage is held for anaerobic action to occur, the production of sulphuretted hydrogen in an amount great enough to be noticed is a rather unusual occurrence. Many of the samples collected from the Fens basin were impregnated with this gas; this occurred under salt-water conditions. Some of the samples of mud and sand from the Charles River basin were more strongly impregnated with this gas than any sewage sludge I have ever examined. In the basin from which these samples were collected, whatever putrefaction occurs is under salt-water conditions.

Experiments upon the mixture of sea water and sewage and fresh water and sewage showed generally little difference in the degree of odor produced immediately, but invariably the sea-water mixture gave the stronger odor after a period of bacterial growth and the exhaustion of oxygen. A number of laboratory experiments were made, comparing the bacterial growths in sea water over mud and fresh water over mud. In the first experiment two glass cylinders about 18 inches high had 2 inches in depth of Charles River mud placed in them, and were then filled with sea water and fresh water respectively. The cylinders were kept at a temperature of 80° F. for twenty-four days, and bacterial analyses were made daily, plates being incubated in duplicate, one set in the air and the other set in hydrogen. The greater number of bacteria were found in the salt water, and by far the greater number of those able to live under anaerobic conditions, *i.e.*, in an atmosphere of hydrogen. Various other experiments were made, by which the relative number of bacteria growing in the water over the mud and in the mud itself was shown under both fresh and salt water conditions. These experimental growths were continued in some instances for four weeks, and, while some contradictory results were obtained, the general results agreed, and were as follows: —

1. The greater number of bacteria in the supernatant liquid were found under fresh-water conditions.
2. The greater bacterial growth in the muds occurred under fresh-water conditions.
3. The greater relative number of anaerobic growths occurred under salt-water conditions, both in the mud and in the supernatant liquids.

4. In the salt-water experiments the number of bacteria which, when the water was plated, would grow in hydrogen, — *i.e.*, under anaerobic conditions, — exceeded in number in some instances those which would grow in air, — *i.e.*, under aerobic conditions.

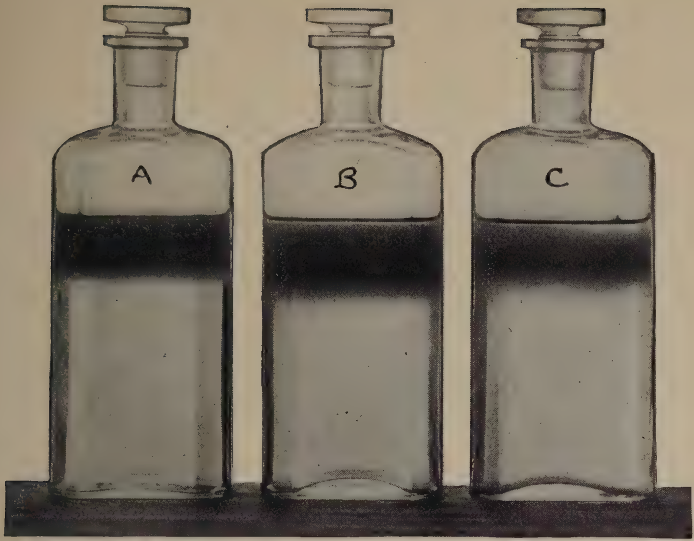
5. The greatest exhaustion of oxygen occurred under salt-water conditions.

Rate of Sedimentation in Salt and Fresh Water.

In the course of this investigation and in connection with observations of the appearance of the river at present during times of storm, certain experiments have been made upon the comparative degree of rapidity with which bodies of turbid fresh water and turbid salt water clear themselves. It has been shown very clearly that salt water acts like a precipitant, especially if the turbidity is caused to some extent by bodies such as are present in sewage. This is true if the matter causing turbidity is well mixed with the water. *If turbid fresh water is placed above salt water, the turbidity will disappear slowly when the water is quiet.* This effect is shown by photographs Nos. 1 and 2, of bottles containing turbid fresh water over clear salt water. Upon Photograph No. 1, A, B and C give the appearance at the start and after one and two hours respectively, while on Photograph No. 2 the appearance after fourteen, fifteen and sixteen hours is shown.

To illustrate the greater rapidity of sedimentation or clearing of turbidity occurring in salt water than in fresh water, five test bottles were prepared, containing respectively (1) sea water, (2) 25 per cent. fresh water and 75 per cent. sea water, (3) 50 per cent. fresh water and 50 per cent. sea water, (4) 75 per cent. fresh water and 25 per cent. sea water, and (5) fresh water. To each of these was added the same amount of Charles River mud, and the bottles were then thoroughly shaken and set aside, observations being made of the appearance at short intervals. After about five minutes all the bottles containing sea water showed a layer of clear water at the top equal to about 20 per cent. of the volume of the bottle. After fifteen minutes these bottles showed about twice as much clear water above the mud as at the end of five minutes, and this appearance was not changed very much during about five hours' observation. After twenty-four hours the layer of turbid water in the bottles had contracted to about one-half its volume at the end of fifteen minutes. (For this last observation a separate experiment was made.)

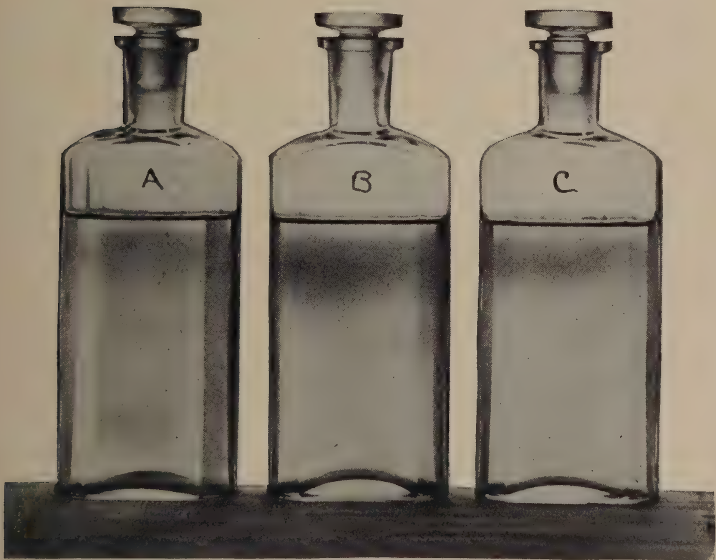
The fresh water behaved quite differently. At the end of one hour the coarser particles of the mud had settled out, but the upper strata were very black and turbid. After from two to three hours a very slight layer of clear water could be observed above the turbid layer, and this layer had not appreciably increased in depth at the end of five hours. After from eighteen to twenty-four hours considerable clear water was seen above the turbid layers, and these turbid layers were stratified, the upper layers being more transparent than those nearer the bottom. Repetitions of this experiment showed that the stratification was not the same in different experiments, apparently being influenced considerably by the temperature and by any slight vibration. The complete sedimentation of the finer particles of the grade which were present appeared to be accomplished in from four to ten days, if the bottles were left undisturbed. A very slight disturbance, however, hastened the sedimentation of the finer particles, and slight changes in the temperature, by forming currents in the bottles, furnished sufficient disturbance in some instances to accomplish this result (see photographs).



PHOTOGRAPH No. 1.

Turbid Fresh Water above Salt, at Start and after standing 1 and 2 Hours.

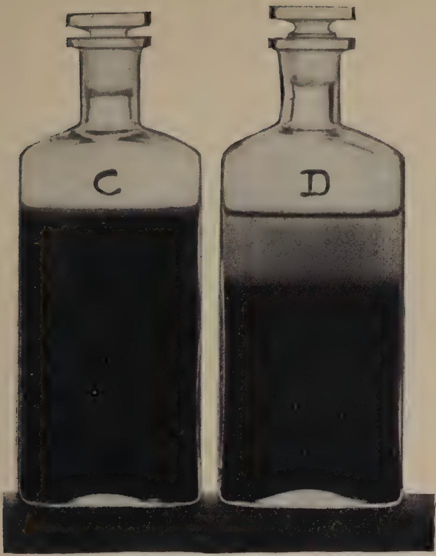
A. At Start. B. 1 Hour. C. 2 Hours.



PHOTOGRAPH No. 2.

Turbid Fresh Water above Salt, after standing 14, 15 and 16 Hours.

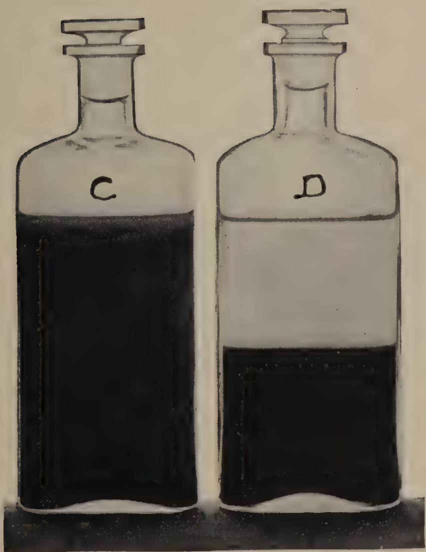
A. 14 Hours. B. 15 Hours. C. 16 Hours.



PHOTOGRAPH No. 3.

Turbid Fresh and Turbid Salt Water after 5 Minutes Sedimentation.

C. Fresh Water. D. Salt Water.



PHOTOGRAPH No. 4.

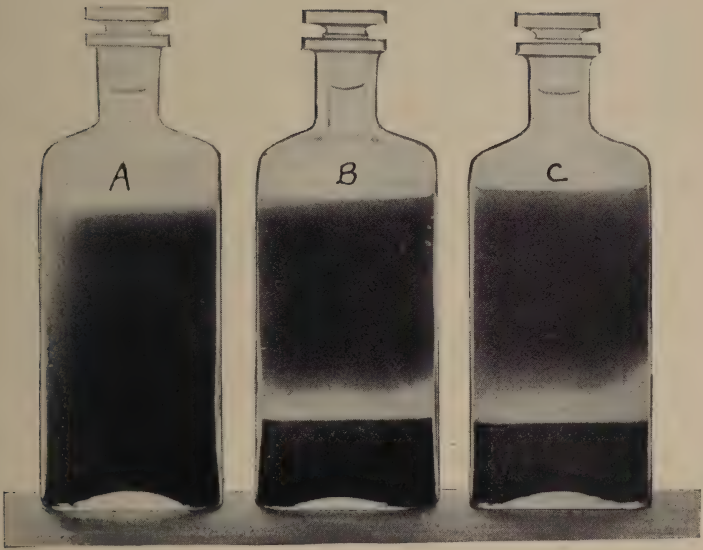
Turbid Fresh and Turbid Salt Water after 15 Minutes Sedimentation.

PHOTOGRAPH No. 5.

Turbid Fresh and Turbid Salt Water after 24 Hours Sedimentation.

PHOTOGRAPH No. 6.

Turbid Fresh Water after 6 Hours Sedimentation.



At Start. 5 Minutes. 10 Minutes.

PHOTOGRAPH No. 7.

Turbid Fresh Water above Turbid Salt Water, showing Precipitation of Sediment in Salt, Fresh Water not clearing.

Photograph No. 3. — C = fresh water; D = salt water; after five minutes' sedimentation.

Photograph No. 4. — Same bottles, after fifteen minutes' sedimentation.

Photograph No. 5. — Shows fresh water on the left and salt water on the right, after twenty-four hours' sedimentation.

Photograph No. 6. — Shows the same effect with fresh water as in Photograph No. 5; three strata were observed with clear water above, and these can be seen in the photograph, on close inspection.

If a layer of turbid fresh water be run carefully upon the surface of turbid salt water in such a manner that the two waters mix but slightly, a peculiar phenomenon is noticed; that is, the finely divided matter in suspension in the salt water begins to precipitate, and shortly a layer of clear salt water appears below the fresh water, which still retains its turbidity. This effect is shown in Photograph No. 7. The bottle on the left shows the appearance immediately after the waters were placed in the bottles, the turbid fresh water having been run upon the surface of the turbid salt water in such a manner that practically no mixing occurred. The bottle in the centre shows the appearance after standing five minutes, and the bottle on the right after standing fifteen minutes.

In case the fresh water in this experimental work contains any heavy particles, these break through the line of demarkation between the fresh and salt water after a short time, and soon cause a mixing of the two waters, with a consequent precipitation of all of the turbidity. This feature may be noticed in the photograph, the coarser particles being seen falling through the layer of clear salt water. Changes in the surrounding temperature, or a difference in the temperature of the two waters, will hasten their intermingling and complete sedimentation. If the waters are of practically equal temperature, and are allowed to remain quiet at a constant temperature, the layer of turbid fresh water may remain on the surface of the salt water for some hours, the turbidity of the salt water in the mean time being entirely precipitated.

The effect of the influx of a volume of salt water under a body of fresh water is much the same as the above, the salt water floating the turbid fresh water without mixing with it to any great extent, if its influx is slow. This effect is shown in Photograph A, which was taken about fifteen minutes after the waters were placed in the bottles, the salt water being run in below the fresh water through a tube.

The Persistence of a Layer of Salt Water at the Bottom of a Basin Distinct from Fresh Water.

Considerable work has been done to study this point by means of samples from the present basin collected at different locations and depths at high and low tide, by samples from the Mystic Lakes at Winchester under similar conditions, and by experimental work. In the lower basin as the tide comes in there is a pretty general mixture of the salt and fresh water, and an apparent pushing back of the fresh water as the basin narrows, as discussed in previous pages. In the upper portion of the basin, where the fresh water is more prominent, it shows, by analysis, above the salt water. As the tide goes out, a large proportion of the fresh water coming down remains in the upper foot of water. The Mystic Lake examinations have shown similar results, but less clearly, owing to local conditions.

As an experiment, I have operated a tank at Lawrence as follows: This tank contained about 5½ feet in depth of water, and was 3½ feet in diameter. It was put into operation on September 29, and was

continued until November 7. The lower layer of water 3 feet in depth was salt, and above this at the start was 2½ feet in depth of polluted fresh water, — that is, having a free and albuminoid ammonia content of .1000 and .0600 parts per 100,000 respectively. The tank was so arranged that fresh water of the character noted flowed in at one side and out at the other very slowly, but at such a rate that the fresh water changed daily. Determinations of chlorine and dissolved oxygen at different depths were made daily, and the results were as follows: —

Tank No. 4. — *Table of Chlorine in Parts per 100,000 and Per Cent. of Saturation of Dissolved Oxygen in Water at Different Depths.*

Day of Month. 1902.	Surface.		6 Inches.		1½ Feet.		2½ Feet.		3¼ Feet.		4½ Feet.	
	Chlorine.	Dissolved Oxygen.	Chlorine.	Dissolved Oxygen.	Chlorine.	Dissolved Oxygen.	Chlorine.	Dissolved Oxygen.	Chlorine.	Dissolved Oxygen.	Chlorine.	Dissolved Oxygen.
Sept. 29, .	1.3	45.0	-	-	38.0	32.0	-	-	1672.0	78.0	1672.0	78.0
Oct. 1, .	9.8	33.3	23.8	14.3	36.0	0.0	505.5	18.7	1662.5	41.6	1665.0	60.2
2, .	4.2	48.4	25.0	14.2	42.0	0.0	1079.0	21.2	1680.0	27.4	1680.0	48.7
3, .	7.0	36.3	24.4	0.0	41.9	0.0	1260.0	2.6	1670.0	18.0	1686.3	25.2
4, .	10.4	23.5	26.3	0.4	53.2	0.3	1522.0	0.8	1675.0	0.7	1702.5	10.7
5, .	13.0	24.6	20.3	6.7	50.7	1.0	1467.0	1.0	1668.8	8.0	1687.5	4.9
6, .	10.9	15.3	22.8	0.0	68.1	0.0	1560.0	0.6	1665.0	4.6	1665.0	4.8
7, .	5.2	8.1	22.8	0.0	55.5	0.0	1519.0	1.0	1638.8	0.7	1658.8	1.0
8, .	6.4	6.2	17.6	0.4	46.1	0.0	1477.0	0.0	1665.0	0.3	1677.5	0.4
9, .	3.2	19.9	8.0	15.3	38.5	0.0	1422.0	0.0	1647.5	0.6	1657.5	0.7
10, .	4.6	20.8	7.5	12.0	34.6	0.0	1340.0	0.0	1645.0	0.3	1651.3	0.6
11, .	3.2	10.9	6.6	11.0	31.9	0.0	1270.0	0.0	1667.5	0.0	1671.3	0.9
12, .	2.3	13.9	6.6	1.9	30.9	0.0	1100.0	0.0	1666.3	0.0	1667.5	0.0
13, .	2.4	37.2	6.9	1.6	29.7	0.0	967.0	0.0	1656.3	0.0	1657.5	0.0
14, .	1.5	21.1	7.0	0.8	28.7	0.0	1079.0	0.0	1627.5	0.0	1657.5	0.0
15, .	3.4	12.9	6.3	0.3	28.3	0.0	931.0	0.0	1651.3	0.0	1677.5	0.0
16, .	3.3	37.0	4.4	4.8	24.9	0.0	802.0	0.0	1651.3	0.0	1665.0	0.0
17, .	3.2	19.8	4.1	6.1	25.3	0.0	752.0	0.0	1617.5	0.0	1650.0	0.0
18, .	3.1	17.6	3.5	10.6	25.2	0.0	752.0	0.0	1627.0	0.0	1652.5	0.0
19, .	0.8	26.7	3.5	7.0	24.2	0.0	718.0	0.0	1632.0	0.0	1697.0	0.0
20, .	1.0	58.1	3.4	1.9	23.3	0.0	722.0	0.0	1632.0	0.0	1697.0	0.0
21, .	2.8	24.4	3.0	21.7	19.1	0.0	513.5	0.0	1632.0	0.0	1697.0	0.0
22, .	2.9	31.8	3.2	29.8	11.5	8.3	436.0	0.0	1607.0	0.0	1662.0	0.0
23, .	2.1	35.9	3.0	28.8	4.9	20.8	366.0	0.0	1607.0	0.0	1652.0	0.0
24, .	2.9	34.0	2.9	25.3	3.2	19.7	327.5	0.0	1607.0	0.0	1652.0	0.0
25, .	2.2	35.9	2.7	18.9	3.1	20.3	275.0	0.0	1607.0	0.0	1677.0	0.0
26, .	2.5	28.9	2.5	23.5	2.9	18.9	238.0	0.0	1632.0	0.0	1677.0	0.0
27, .	1.6	48.3	2.2	32.0	2.5	13.0	209.3	0.0	1622.0	0.0	1667.0	0.0
28, .	2.5	62.5	8.1	0.8	12.7	0.3	431.0	0.0	1514.0	0.0	1571.0	0.0
29, .	2.6	51.3	7.0	0.0	12.1	0.0	394.0	0.0	1512.0	0.0	1572.0	0.0
30, .	6.1	23.8	5.9	14.6	11.9	0.0	361.0	0.0	1505.0	0.0	1572.0	0.0

A study of the table will show that there was a constant tendency for the waters to mingle slightly, and at the end of a month the water at a depth of 4½ feet contained about 6 per cent. by volume of fresh water. It will also be noticed that, while the fresh water or at least its upper layers always contained dissolved oxygen, the free oxygen in the salt water was exhausted at the end of twelve days, even at the depth of 4½ feet, this being hastened by the constant precipitation of organic matter from the fresh water.

Upon October 27 a considerable amount of Charles River mud was placed in the bottom of the tank, and following this, conditions and odors were obtained in the salt water somewhat similar to those in the Fens, but to a less degree.

SUMMARY.

Summarizing all this work, together with additional observations and notes, I reach the following conclusions: —

1. The main body of salt water now flowing into the basin on the flood tide, as shown by the various examinations and analyses, is practically odorless and contains free oxygen. The amount of nitrogenous organic matter present in it is from two to three times as great as that in unpolluted sea water. Its degree of pollution is fairly constant day after day, showing that, even if a large portion of the water flowing from the estuary upon one tide returns upon the next, still, the polluting matters are quite well cared for by dilution, sedimentation and oxidation.

2. The water flowing over Watertown dam throughout the greater portion of the year contains but little more organic matter than the salt water now filling the basin, and it contains a plentiful supply of free oxygen. This water is low in color, practically odorless, and, with the exclusion of some of the wastes entering below Waltham, would be suitable for a public water supply, as far as organic matter is concerned. The drainage entering the river above the dam, however, and the bacteria present because of this drainage, would prohibit its use for this purpose without filtration, but not for the purpose for which the basin is intended. In the summer, when the volume of water flowing over Watertown dam is less under ordinary conditions than during the remainder of the year, the organic matter present is considerably greater, volume for volume, than during the larger part of the year. This is of course due to the fact that the same volume of industrial wastes, etc., enters, and is less diluted owing to the smaller flow. The summer flow presents an unattractive appearance at times at Watertown dam, owing to its discoloration with dye stuffs, wool-scouring liquor, etc. A very small proportion of the water, at such times, however, contains enough organic matter to exhaust the oxygen present even when incubated for five days at 80° F. The organic matter in this water would not, owing to its nature and limited amount, putrefy under summer conditions in a still basin, where there is constant surface exposure and the introduction of oxygen; in fact, decomposition — the change of organic matter in the *presence* of oxygen — would go on slowly, and the water would improve. Certain of these wastes entering the river at and above Watertown dam should be excluded, however, if the upper section of the basin is to present an attractive appearance at all times.*

3. At least some of the wastes entering Stony Brook — new and old channels — should be prevented from entering, and thus be kept out of the river. The chief and most constant pollution of the new channel,

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* I have already mentioned that Lawrence, Mass., takes its water supply from the Merrimack River, the water being filtered. Not to mention other pollutions, this river receives, eight or nine miles above the intake of the Lawrence water works, the sewage of the city of Lowell, with a population of about 95,000. It also receives the mill wastes of this manufacturing city. The river is dammed at Lawrence, and the pond so formed reaches to within a short distance of Lowell. This stretch of river is attractive enough to have upon its banks many summer cottages and camp houses, occupied throughout the summer season, when this section of the river is also used extensively for boating and bathing. It has also upon its banks a large, well-patronized summer amusement resort, maintained by an electric railroad which runs along the banks of the river.

The Charlestown district of Boston and the cities of Chelsea, Somerville and Everett formerly drew their water supply from Upper Mystic Lake in Winchester. This lake was once a tidal basin at the head of the Mystic River, but the construction of a dam raised the level of the lake 7 feet above high tide, and increased its area by flooding a large amount of flat land at its upper end. Its area at the present high-water mark is 200 acres, and it is very deep in nearly all portions. The lake receives its principal inflow from the Abbajona River, which enters the lake at its northerly end; and during

judging from the observations of the past two months, is from a brewery or breweries at Forest Hills. The water flowing in the channel above this brewery is entirely suitable, under normal summer conditions, for entrance into the Fenways and the proposed Charles River basin; below, it is offensive and putrescent. Other objectionable sewage and drainage, apparently in small amounts except at times of storm, enter the new channel. The drainage flowing from the old channel, judging from our examinations, averages somewhat lower in organic matter than that from the new channel.

4. Objectionable pollution enters the river from the outlet of Muddy River and from sewer overflows.

5. Offensive wastes from industrial establishments enter at one or two places between Watertown dam and Craigie bridge.

6. The sewage entering from the houses on Beacon street is plainly evident on the river, especially at low tide, and should be excluded.

7. It is exceedingly improbable, in view of the results of the experiments given, that all the wastes now entering the basin would under any circumstances rob the still fresh water in the proposed basin of its dissolved oxygen. The experiments upon the exhaustion of dissolved oxygen, given in detail in previous pages, were made to show the limit of pollution, or pollution within a given time, which water can receive without exhaustion of oxygen and without the production of offensive odors. Because oxygen remained in the water when polluted to the degree indicated in the Tank No. 3 experiment, however, is no reason for assuming that such a condition of pollution would be allowable as a normal condition in the basin; but it does indicate to what extent of pollution the water might at times reach without the exhaustion of oxygen and hence without serious offence. If, as stated

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the time that this lake was used as a water supply much sewage and factory waste found its way into the river, and thus entered the upper end of the lake. Thirteen analyses of the water of the Abbajona River, made by the State Board of Health during 1891, and December, 1890, gave the following result: —

[Parts per 100,000.]

Ammonia.				Chlorine.	Nitrogen as	
Free.	Albuminoid.				Nitrates.	Nitrites.
	Total.	In Solution.	In Suspension.			
.0412	.0349	.0265	.0084	1.91	.0968	.0021

Twelve analyses, made by the State Board of Health during 1891, of the water from the lower end of the lake, at the point from which the supply for the districts already mentioned was taken, gave the following result: —

[Parts per 100,000.]

Ammonia.				Chlorine.	Nitrogen as	
Free.	Albuminoid.				Nitrates.	Nitrites.
	Total.	In Solution.	In Suspension.			
0186	.0242	.0187	.0055	1.58	.0731	.0012

That is to say, into this small lake a stream entered which at that time was receiving a considerable amount of pollution, enough so that its average analysis was as given above, and yet the water from the lower end of the lake was drawn for a public water supply. While from a water supply point of view this water was turbid and at times had a disagreeable odor, still the lake is reported to have been of an attractive appearance.

on previous pages, the sewage of more than 13,000 people, amounting to 1,000,000 gallons per day, should enter the basin daily, it would require more than a month's flow to cause the volume of entering sewage to reach 1 per cent. of the capacity of the basin. As the experiments show, however, the volume of sewage entering each day could certainly for a considerable period, without causing offence, amount to thirty-three times this, or 1 per cent. of the capacity of the basin *if this sewage was well distributed throughout the waters of the basin.*

8. The basin would, under present conditions of sewage pollution, etc., present an unattractive appearance at times of storm. The appearance, however, would be no worse than it now is at times of storm, especially at low tide.

9. There would be no more odor at such times — *i.e.*, times of storm — than there is now; in fact, probably less odor, as much now comes from the uncovered mud flats at low tide.

10. With such drainage removed as has been indicated in this report, the water of the basin would always contain a plentiful supply of free oxygen, even though at times of storm a large volume of sewage should enter from the overflows.

11. Certain mud banks should be removed, although it is possible that the organic matter contained in them would gradually disappear by decomposition. This organic matter forms, however, but a very small portion of these deposits, as the table of loss on ignition, given on page 278, shows.

12. It is hardly possible, and certainly not probable, that any of the mud banks, with two or three exceptions, contain enough organic matter to decay rapidly enough, even in a still basin, to rob the water of its oxygen and over-saturate it with the gaseous products of decay. Moreover, even with the dam built, it could not possibly be a basin of still water, as there will always, even in the dryest seasons, be a slight current, and such movements of the water as are caused by wind and changes in temperature.

13. With water of the character of that flowing from the Fens from various drains, etc., often devoid of oxygen, the mud banks would aid in tending to cause a nuisance.

14. Better conditions would prevail with the basin filled with still fresh water than if filled with still salt water or brackish water; that is, certain experiments and observations already given seem to show that in a basin with a bottom of Charles River mud and with certain drainage entering, better conditions prevail if the water is all fresh, than when salt, or when the bottom layer of water is salt with fresh water above. There is the constant tendency for precipitation to occur in salt water, and hence concentration of the organic matter of entering sewage in the form of putrefying sludge banks; while in fresh water more even mixing and distribution of this matter throughout the oxygen-bearing water occurs. The examinations of water from different depths in the Fens, where the bottom layer is salt, also go to prove this statement. The fresh surface water entering the Fens is badly polluted, and constant deposition of organic matter is taking place, causing putrefaction and the exhaustion of oxygen from the salt water.

15. There is a certain popular belief that running water purifies itself more quickly than still water; the fact is, however, that, with oxygen present in the still water and as good conditions for proper bacterial growths, the still water purification is at least as energetic as the purification occurring in running water. If two equally polluted waters are kept under the conditions obtaining in the experiment given on previous pages, of still water and dripping water, the rapidity

of purification is practically equal as long as both contain dissolved oxygen.

16. Under present conditions at times of storm, the turbid water flowing into the Charles River basin is carried over large areas by the movement of the tides, especially as, being fresh water, it flows over the surface of the salt water. It is doubtful if in a still basin the turbid water would be carried over these large areas, as it would mingle with the entire depth of water, especially if this water were fresh.

17. There remains to be spoken of the possible growth of algæ in the basin, and odors caused by its decomposition. Growths of organisms are likely to occur in almost any pond, and in some of the water supplies of the State certain growths occur which by their life or death cause trouble at times by producing tastes and odors noticeable to the consumers of these waters. These are not cases of nuisance at the ponds or reservoirs, however, but at the taps. Large growths of algæ sometimes occur, which, by becoming stranded on the shores, owing to a lowering of the water level, produce odors when decaying. In the proposed basin, however, with a constant level and with steep shores, such algæ growths as may occur would, when dying and falling to pieces, probably mingle with the water.

Respectfully submitted,

HARRY W. CLARK.

Appendix No. 5.

Sanitary Engineer's Report

CONCERNING

THE PROPORTIONATE AMOUNT OF POLLUTION THAT A POND OR STREAM OF FRESH WATER CAN RECEIVE WITHOUT THE PRODUCTION OF OFFENSIVE ODORS OR OFFENSIVE APPEARANCE, MAINLY AS SHOWN BY EXPERIENCE WITH THE WATERS OF MASSACHUSETTS DURING THE PAST TEN YEARS.

By X. H. Goodnough, *Civil Engineer.*

Boston, Mass., Dec. 18, 1902.

Mr. John R. Freeman, *Engineer, Committee on Charles River Dam.*

Dear Sir: — In response to your request to furnish you with the fullest possible statement of the cases which have come under my observation where the quantity of sewage falling into a pond or flowing stream is anywhere near that liable to occur in the case of the proposed basin on Charles River, I present you herewith the results of observations that I have made and information that I have collected as to the discharge of sewage into the various ponds, rivers and streams in this Commonwealth.

These investigations have included examinations of the water-sheds of the streams; the distribution of population thereon; the location of dams and reservoirs; measurements of the flow of the streams; determinations of the quantity and character of the sewage and manufacturing wastes discharged into the streams; and of the character of the normal water of the streams and of the water at various points in their courses, especially above and below sewer outlets.

Natural Character of Waters of Rivers and Ponds.

The water-sheds of the various streams in the State differ widely in topography, and there is consequently a wide difference in the natural character of their waters. This difference may be illustrated by comparing the two following analyses, which represent the averages of several determinations from two sparsely populated water-sheds, — in one case of a water flowing from a water-shed of about 50 square miles in the westerly part of the State (middle branch of Westfield River), and in the other from a water-shed of about 38 square miles in the south-eastern part of the State (Wenatuxet River). No sewage or manufacturing waste of consequence finds its way into either stream.

Chemical Examination of Water from the Middle Branch of the Westfield River at Huntington, Mass., and from the Wenatuxet River at Halifax, Mass.

Middle Branch of Westfield River.

[Parts per 100,000.]

Month.	Appearance.			Odor.		Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
									Albuminoid.							
	Turbidity.	Sediment.	Color.	Cold.	Hot.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
July,	None.	V. slight.	0.10	None.	None.	3.00	1.25	.0004	.0088	.0078	.0010	.06	.0000	.0000	0.30	1.6
December,	None.	V. slight.	0.15	None.	Faintly vegetable.	3.50	1.50	.0004	.0064	.0052	.0012	.10	.0050	.0000	0.21	1.6

Wenatuxet River.

Month.	Turbidity.	Sediment.	Color.	Cold.	Hot.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Hardness.
July,	V. slight.	Cons.	2.30	V. faintly vegetable.	Distinctly mouldy.	6.60	2.85	.0038	.0420	.0368	.0052	.46	.0120	.0003	-	-
December,	V. slight.	Cons.	2.10	Distinctly vegetable.	Decidedly vegetable.	7.25	4.00	.0044	.0264	.0236	.0028	.70	.0040	.0000	1.74	1.4

In these and subsequent analyses the quantity of albuminoid ammonia may be taken to represent the quantity of organic matter present. It will be seen, by comparing these analyses, that the water of the Wenatuxet River is very highly colored and contains a very large quantity of organic matter, as shown by the albuminoid ammonia, compared with the color and the quantity of organic matter in the water of the middle branch of the Westfield River. The excessive color and organic matter in the water of the Wenatuxet River is due to the contact of the water with vegetable matter in swamps along the stream and its tributaries; and examinations and experiments with many such waters have shown that organic matter of this sort is very permanent in character, and will remain constant in composition for months without developing indication of decay. The waters of many of the streams of the State having water-sheds containing considerable areas of swamp and meadow land contain naturally much organic matter of this sort, and it is essential that this fact be borne in mind in considering the condition of river waters, and in comparing them by chemical analysis.

The waters of some of the ponds and reservoirs in the State which are practically free from pollution by sewage or manufacturing waste contain at times very large quantities of albuminoid ammonia, and at such times large numbers of microscopical organisms are usually present in the water. Jamaica Pond, for example, at times during the period when it was used as a source of water supply contained great quantities of albuminoid ammonia, the quantity at one time amounting to as much as 0.18 of a part per 100,000, or as great a quantity as is found in dilute sewage. Numerous other similar instances are given in the published analyses of waters of various sources in the State.

Such ponds and reservoirs are not, however, nuisances to those living in the neighborhood at such times, and objectionable odors are very rarely noticeable except to those who use the water for domestic purposes.

On the other hand, the water of Mystic Lake, though greatly polluted by sewage and manufacturing waste from the dense population on its water-shed, was never found to contain an excessive quantity of albuminoid ammonia at the place at which it was drawn for many years for the supply of Boston, Somerville, Chelsea and Everett; and the same was true of Lake Cochituate, which was polluted for many years by the water of brooks entering the southerly end of the lake.

The waters of the rivers of the State and the ponds along their courses have not been found to be affected by considerable growths of microscopical organisms, such as are often present in ponds and reservoirs in which the water changes very slowly.

A consideration of the results of investigations of numerous sources, covering many years, shows that the determination of albuminoid ammonia does not in itself convey any information as to the character of organic matter in water; and, to determine the significance of albuminoid ammonia in a given water, it is necessary to make certain other determinations, and to have a knowledge of the source of the water and the circumstances by which its character may be affected.

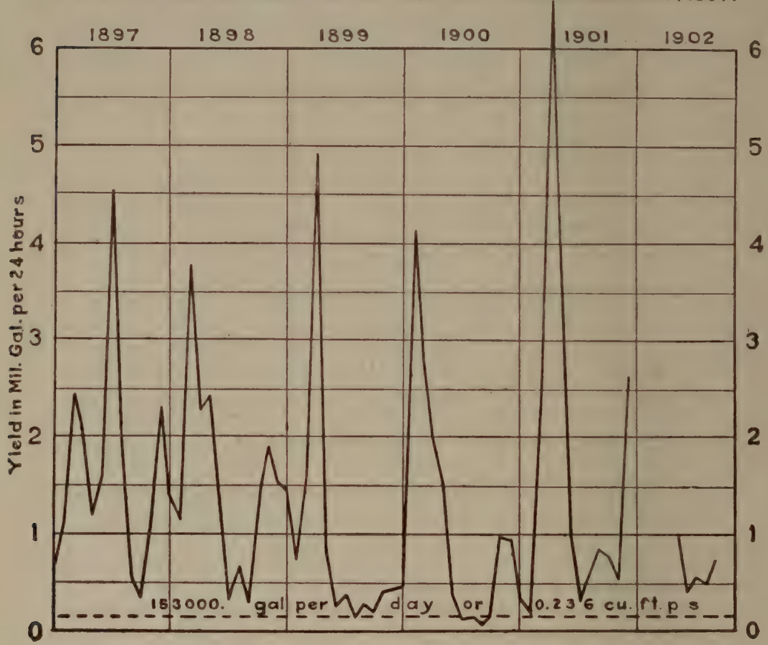
Flow of Streams.

The flow of streams in Massachusetts varies greatly in different seasons of the year, the flow in the winter and spring being ordinarily many times as great as in the summer and fall. The wide difference between the flow of a stream in the winter and spring and its flow in summer is illustrated by the accompanying diagrams, showing the average monthly

flow of two carefully measured streams for many years. These diagrams also show that there is in many cases a very wide difference in the flow of a stream during corresponding periods in different years.

The flow of streams given in the illustrations represents the natural flow from these water-sheds; that is, the quantity of water which reaches the stream from the rainfall by direct flow over the surface of the ground or by gradual percolation through the soil. There are water-sheds which contain extensive areas of coarse, sandy or gravelly soil,

DIAGRAM SHOWING AVERAGE DAILY FLOW PER SQ. MILE OF WATERSHED OF A RIVER IN WESTERN MASSACHUSETTS FOR EACH MONTH SINCE JANUARY, 1897.



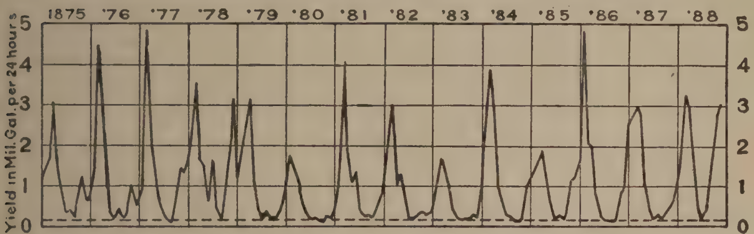
which absorb much water from the rainfall in the winter and spring and yield it gradually to the streams in the drier portion of the year, thus maintaining a higher flow in the latter season than water-sheds containing a more compact soil; and there are streams which become entirely dry in places, owing to percolation of all the water in dry weather through underground channels.

The natural flow of nearly all streams in Massachusetts has, however, been modified to a greater or less degree in the development of water powers by the construction of dams and by the use of natural lakes and ponds or artificial reservoirs for the storage of water in the wetter portion of the year, for use in maintaining the flow of the stream in the drier portion. The increase in the dry-weather flow of streams maintained by the use of storage reservoirs is in some cases very small, but in the case of most of the larger streams in the State it is considerable; and in a very few cases the storage capacity upon the water-shed is so great that the flow maintained in summer approaches closely the average flow for the year.

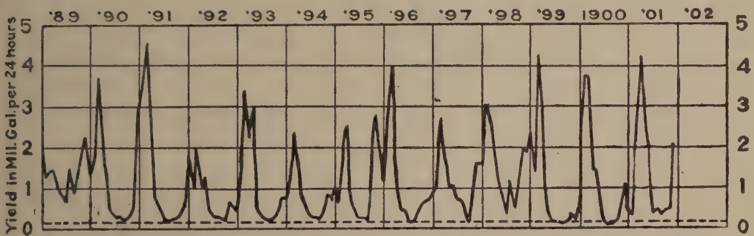
The differences between the flow of streams in the winter and spring and the flow in the warmer months of the year is very much greater

than the differences in the flow of sewage from a city or town at different seasons, as will be shown further on; and in cases where the sewage of a city or town is discharged into a stream, the ratio of the quantity of sewage to the quantity of water flowing in the stream is ordinarily much greater in the drier portion of the year than in the winter and spring. Moreover, when objectionable conditions are caused by the pollution of streams they are much more noticeable in warm weather than at other times. It is, therefore, necessary in studying the effect of

DIAGRAM SHOWING AVERAGE DAILY YIELD OF ONE SQ. MILE OF LAND SURFACE ON THE SUDBURY RIVER WATERSHED FOR EACH MONTH SINCE JANUARY, 1875.



Dotted line shows flow of 153 000-gal. per day, or 0.236 cu. ft. per sec.



Dotted line shows flow of 153 000-gal. per day, or 0.236 cu. ft. per sec.

sewage upon a stream to consider the conditions existing in the warmer and drier portion of the year.

An examination of the diagrams of flow of streams already presented will show that in every year there is a dry period when the flow is very much lower than in the other months, and that in a few of the years a period of very low flow continues for as many as five or even six months. The longest period of extreme low flow has been selected, as representing the most unfavorable conditions under which sewage may be discharged into a stream under ordinary conditions, and the flow for the streams given in the diagrams for this period is represented by a dotted line. The flow of these streams is unaffected by storage or extraordinary conditions. It will be noted that there are occasional periods of short duration when smaller flows have been observed, but the flow for previous and succeeding months was much higher.

Quantity and Character of Sewage from Cities and Towns.

There is a great difference in the quantity of sewage flowing from districts of the same size and population, and in the quantity of organic matter contained in the sewage. These variations are caused by differences in the quantity of water used and wasted, in leakage of ground water into the sewers, in the quantity and kind of manufacturing wastes discharged into the sewers and by other circumstances. There is also a very material variation in the quantity of sewage flowing from the same

district at different seasons of the year and at different hours of the day.

In the following table is given the quantity of albuminoid ammonia in the sewage of four cities and towns in which very little manufacturing waste is discharged into the sewers, determined from the results of numerous samples collected at frequent intervals, and the calculated quantity of albuminoid ammonia that these amounts would represent if this quantity of organic matter had been contained in 100 gallons of water for each person connected with the sewers.

City or Town.	Albuminoid Ammonia. (Parts per 100,000.)	Calculated Quantity of Albuminoid Ammonia on Basis of 100 Gallons per Person connected with the Sewers.
Andover,	.55	.32
Brockton,	.91	.34
Marlborough,	.28	.30
Spencer,	.25	.35

These results and the results of numerous other examinations of sewage indicate that the quantity of organic matter in ordinary sewage depends rather upon the population discharging sewage into the sewers than upon the actual flow from the sewers, and that the total quantity of organic matter discharged from a given population is approximately the same, whether the flow of sewage is large or small.

The quantity of sewage flowing from a city or town, as already stated, varies within narrow limits compared with the variation in the flow of streams, although the flow of combined sewers fluctuates much at times of rain.* In the following table is given the average monthly flow of a stream and the records of the flow of sewage from a town having a separate system of sewers, in which no extraordinary conditions affect the flow: —

Table showing Monthly Flow of a River compared with the Monthly Flow of Sewage in the Year 1900.

Month.	Flow of Stream (Gallons per Day per Square Mile).	Flow of Sewage (Gallons per Day).	Ratio of Stream Flow to Sewage.
January,	475,000	495,000	.96
February,	4,150,000	639,000	6.49
March,	2,800,000	758,000	3.70
April,	1,980,000	694,000	2.86
May,	1,521,000	651,000	2.34
June,	374,000	608,000	.62
July,	149,000	361,000	.41
August,	169,000	328,000	.52
September,	79,000	332,000	.24
October,	182,000	417,000	.44
November,	993,000	477,000	2.08
December,	951,000	739,000	1.29
Average for year,	1,131,000	542,000	2.09

* In such places the sewage is diluted at times of rain or when snow is melting, and the flow greatly increased; but the quantity of sewage proper, while diffused through the great quantity of water, is not increased, though a small quantity of organic matter may be brought into the sewers in the rain water from street surfaces, etc.

The variation in the quantity of sewage at different times is accompanied by a similar variation in the strength of the sewage, the strongest sewage being found at the times of least flow and the weakest sewage at the times of highest flow.

The variation in the quantity and character of sewage discharged from a system of sewers at different hours of the day is illustrated by the following table, showing the daily variation in the rate of flow and character of sewage: —

Table showing Daily Variation in Rate of Flow and Character of Sewage.

[Parts per 100,000.]

Hour.	Rate of Flow (Gallons per 24 Hours).	Residue on Evaporation.						Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	
		Total Residue.			Loss on Ignition.				Albuminoid.							
		Total.	Dissolved.	Suspended.	Total.	Dissolved.	Suspended.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	Unfiltered.	Filtered.
9.00 and 10.00 A.M.,	254,200	46.60	28.40	18.20	26.60	12.00	14.60	3.5000	.8900	.4100	.4800	3.81	.0010	.0000	5.76	2.69
11.00 and 12.00 A.M.,	239,400	52.20	35.80	16.40	29.60	15.80	13.80	3.6500	.7700	.3900	.3800	4.40	.0020	.0000	6.16	3.81
1.00 and 2.00 P.M.,	254,300	42.00	29.40	12.60	21.00	11.00	10.00	2.5000	.5300	.2800	.2500	4.92	.0010	.0000	4.00	2.34
3.00 and 4.00 P.M.,	239,800	46.40	25.80	20.60	28.00	11.00	17.00	2.6500	.7000	.3000	.4000	4.65	.0020	.0000	5.12	3.17
5.00 and 6.00 P.M.,	220,900	40.20	30.80	9.40	17.20	9.00	8.20	2.7000	.4900	.2600	.2300	8.39	.0020	.0000	3.36	1.89
7.00 and 8.00 P.M.,	213,200	31.60	23.60	8.00	15.20	9.80	5.40	3.3000	.5800	.4100	.1700	4.47	.0020	.0000	4.00	2.21
9.00 and 10.00 P.M.,	189,300	22.00	17.00	5.00	11.00	7.40	3.60	1.9500	.3300	.2000	.1300	2.90	.0010	.0000	3.12	1.57
11.00 and 12.00 P.M.,	175,900	27.40	17.20	10.20	17.60	9.20	8.40	1.7500	.4300	.2000	.2300	2.99	.0020	.0000	3.62	1.76
1.00 and 2.00 A.M.,	152,000	11.40	9.80	1.60	5.00	3.60	1.40	.8200	.1520	.0800	.0720	2.03	.0010	.0120	.80	.59
3.00 and 4.00 A.M.,	145,300	9.40	8.80	.60	3.00	3.00	.00	.1840	.0760	.0400	.0360	1.45	.0510	.0072	.58	.40
5.00 and 6.00 A.M.,	158,300	10.60	9.80	.80	4.20	4.00	.20	.3720	.0680	.0440	.0240	1.50	.0580	.0072	.70	.53
7.00 and 8.00 A.M.,	235,900	22.60	16.60	6.00	12.00	6.40	5.60	2.3500	.4300	.2000	.2300	2.35	.0010	.0000	3.00	1.39
Average for 24 hours,	206,500	32.60	22.50	10.10	17.30	9.10	8.20	2.3300	.4960	.2540	.2420	3.86	.0080	.0020	3.64	2.02

Manufacturing Wastes.

Manufacturing wastes of various kinds are important factors in the pollution of streams in Massachusetts. The manufacturing wastes which have the greatest effect in polluting streams and which are most commonly met with in this State are the wastes from woollen mills, including the wastes from the scouring of wool and the washing and dyeing of cloth; wastes from tanneries, paper mills, shoddy mills, print works; and from rubber mills, silk factories, gas works and other sources less commonly met with. The wastes from the processes of wool scouring and cloth washing usually contain very large quantities of organic matter, and are very serious sources of pollution of streams at many places. The quantity of water used varies greatly at different mills. Waste liquors from the process of dyeing contain, as a rule, comparatively little organic matter; but such liquors discolor streams, and may make them unsightly for a considerable distance below the point at which the liquor is discharged.

When sewerage systems are available for the disposal of these wastes, they can generally be disposed of most satisfactorily by being discharged into the sewers; and this method of disposal is used for the wastes from wool scouring and cloth washing at several places.

Tannery wastes contain great quantities of organic matter, and the quantity of such wastes from a large tannery may amount to as much as the flow of sewage from a town of considerable size.

Wastes from paper mills come largely from the washing of rags and paper used for stock and from the water used in the paper machines. The waste from the washing of stock contains usually much organic matter, and the quantity is large, as much water is used.

The wastes from shoddy mills contain much dirt from the washing of the stock, and large quantities of acid are used in the processes carried on in such mills.

Characteristic analyses of some of these wastes are appended: —

Chemical Analyses of Wastes from Various Manufacturing Processes.

Waste from Washer in Paper Mill.

[Parts per 100,000.]

Rate of Flow (Gallons per Day).	Residue on Evaporation.						Ammonia.				Chlorine.	Oxygen Consumed.	
	Total Residue.			Loss on Ignition.			Free.	Albuminoid.					
	Total.	Dis-solved.	Sus-pended.	Total.	Dis-solved.	Sus-pended.		Total.	Dis-solved.	Sus-pended.		Un-filtered.	Filtered.
200,000	321.60	152.00	169.60	128.80	52.60	76.20	.0500	.4200	.3900	.0300	–	35.00	26.50
Waste from Paper Machine.													
500,000	57.00	37.20	19.80	29.20	16.80	12.40	.0496	.0680	.0264	.0416	–	7.32	4.56
Waste from scouring of Wool.													
400,000*	147.40	75.60	71.80	34.00	12.40	21.60	.0680	.5800	.2900	.2900	–	5.80	4.80
21,000†	1696.00	–	–	1103.00	–	–	6.1000	12.0700	5.8800	6.1900	25.56	136.20	–
Waste from washing Woolen Cloth.													
320,000‡	2621.40	1881.60	739.80	1899.00	1344.60	554.40	1.8200	14.8000	8.4000	6.4000	–	760.00	725.00
Waste from a Tannery.													
200,000	–	–	–	–	–	–	1.8158	5.7000	2.5200	3.1800	46.31	71.37	–
Waste from Dyeing.													
80,000	268.20	260.00	8.20	113.60	108.00	5.60	1.7000	1.2400	.6100	.6300	–	77.50	75.50
–	160.00	149.40	10.60	23.80	18.00	5.80	1.4300	.2100	.1800	.0300	73.20	20.00	10.00

* 2,000 pounds of wool per day. † 4,000 pounds of wool per day. ‡ A very large mill.

Detection of Sewage Pollution in Streams.

There are no water-sheds of any considerable size in Massachusetts which do not contain human habitations, and consequently there are no streams of considerable size which are not affected in a greater or less degree by sewage pollution.

The presence of sewage in water, even in very small quantities, can usually be detected by a determination of the quantity of chlorine present above the normal for the source, since chlorine is a characteristic ingredient of sewage, and the quantity present in ordinary sewage is very much greater than in any natural water, except in those sources very close to the sea.

When sewage enters a stream indirectly, after filtration through the ground, the organic matter has largely been converted to mineral matter, and rendered innocuous, and it is generally impossible to detect the presence of the sewage otherwise than by the chlorine. Where sewage enters a stream directly, it is generally possible to detect it not only by the chlorine, but by the increase in the quantity of organic matter in the water; but where the quantity entering is very small in comparison with the quantity of water flowing in the stream, it is difficult to determine its presence by chemical analysis except perhaps within a few feet of the outlet, the sewage quickly becoming diffused in the water, and its form changed by the action of organisms and by oxidation.

As the quantity of sewage discharged into a stream increases, its presence becomes more readily detectable by chemical and bacterial analysis, and at greater distances from the outlet, until a condition may be reached where the presence of the sewage in the water becomes obvious to the senses. Where sewage is discharged directly into a stream, the effect will, generally speaking, be in proportion to the quantity of sewage discharged. Storage of a polluted water in a pond or reservoir tends to greatly reduce the effect of pollution.

Conditions affecting the Disposal of Sewage in Streams.

Nearly all of the streams in Massachusetts included in the investigations have a considerable fall, which has been largely utilized for manufacturing purposes by the construction of dams and the creation of numerous mill ponds and reservoirs; and, in consequence, there is a large number of places in the State where the sewage of a city or town is discharged into a stream upon which there are dams at greater or less distances below the sewer outlets, creating in some cases ponds in which the water changes very slowly.

Portions of the matters discharged into a pond or stream with sewage doubtless settle to the bottom, where the organic matters decompose and resulting products are carried away in the water, while mineral matters, if heavy, like sand, may remain near the sewer outlet. In places where large quantities of sewage have been discharged into streams or mill ponds for several years, little evidence has been found of the accumulation of matters from the sewage excepting sand and similar matters brought down by the sewers, which are deposited near their outlets. The quantity of solid matter which has been discharged in sewage into some of the mill ponds in the State has already been sufficient to have filled them several times, yet little deposit is noticeable, and it is evident that accumulations, in places where deposits occur, take place slowly.

In some of the places examined the waters of the stream and its beds and shores are rendered filthy and offensive by the sewage, while in

others the effect of the sewage is not noticeable unless in the neighborhood of a badly chosen outlet.

The sewage discharged into a pond or stream may be objectionable, or not, in the neighborhood of the outlet, depending upon the location of the outlet with reference to the stream or pond, and the conditions in its neighborhood. Objectionable nuisances exist at many places where sewage is discharged into streams or ponds, even in places where the flow of the stream and the quantity of water available for the removal of the effect of the sewage are very great in proportion to the quantity of sewage, on account of the manner of discharging the sewage, or the conditions existing in the neighborhood of the outlet. Many sewer outlets are located above the high-water mark and at a considerable distance back from the bank of a stream or pond; and the sewage spreads over a considerable area, and collects in pools before reaching the water. Other outlets are located near the bank of the stream or pond, in shallow pools or bays, into which little or no water finds its way. At many places where sewage is discharged at the edge of a stream the conditions are not objectionable at high water; but, as the water recedes in dry weather, the sewage spreads over a considerable area of the exposed bottom of the pond or stream, which then becomes offensive. In some of the places where such nuisances caused by sewer outlets have existed the sewer has been extended out under the stream or pond, and the sewage discharged at a considerable distance from the shore; and in such cases the objectionable conditions have been removed, and the presence of the outlet is not noticeable unless the quantity of sewage is excessive in proportion to the flow of water.

Offensive conditions may also be caused by sewer outlets located below dams over which there is insufficient flow of water for considerable periods to remove the effect of the sewage.

The discharge of sewage into a stream may be objectionable for other reasons also, though the effect of the sewage upon the appearance of the stream might not be noticeable, as, for example, in cases where a stream is used as a source of water supply below the point of discharge of the sewage, or where the discharge is into tidal waters, from which shell-fish are taken; for some manufacturing and mechanical uses, also, a sewage-polluted water may be objectionable.

Observations upon the discharge of sewage into water at many places show that there is much advantage in discharging it at several outlets, since the sewage then mingles much more rapidly with the water, and is subjected more quickly to those actions which tend to remove its effect.

Summary of Results of Observations.

At many of the places in the State where sewage is discharged into streams, samples of the water of the stream have been collected at frequent intervals for several years, and the average of those results during the drier months of the years 1900, 1901 and 1902 are presented. At most of the places a special examination has been made, which includes measurements of the flow of the stream and of the quantity of sewage discharged into it, together with chemical analyses of the sewage where practicable, and of the water of the stream at various points.

The results of the investigations made and the information collected as to the discharge of sewage at the various places in the State have been summarized, and a statement of those conditions which are of importance in considering the effect of sewage upon the stream has been submitted to you and will only be referred to briefly here.

In order to show the results of the investigations in such a manner that the general conditions at the different places can readily be seen,

a table has been prepared, containing a statement of many of the more important conditions at each place, and is here presented.

In the first column of this table is given the name of the stream and of the place or portion of the stream considered. The second column contains the area of water-shed of the stream at some point, generally at a dam below the place at which the river receives pollution. The third column gives the estimated dry-weather flow of the streams. In the fourth column is given the population discharging sewage, which is usually considerably less than the total population of the place or places from which the sewage is discharged. In the fifth column is given the dry-weather flow of the stream, in cubic feet per second, for each 1,000 persons discharging sewage, made up from columns 3 and 4. The sixth column gives the distance to the next dam below the sewer outlets in cases where dams exist, and the seventh column the number of days of dry-weather flow of the stream required to change the water in the mill pond. In the eighth to the thirteenth columns are given, for many of the places, the average quantities of free and albuminoid ammonia found in the water in the six months of the drier portion of the years 1900, 1901 and 1902, at points below the sewer outlets, determined from results of analyses of samples of the water collected monthly.

The places presented in the table are arranged in the order of the flow of the streams per 1,000 persons discharging sewage.

In summarizing the results of the information available as to the effect of the discharge of sewage into streams in Massachusetts, I omit from this report a discussion of objectionable sewer outlets where nuisances exist by reason of the manner of the discharge of sewage, such as the discharge of sewage upon the bank of a river or pond, where it spreads out over the ground, or where the sewage collects in pools at the edge of a stream or pond, or where the bottom of a pond or stream receiving sewage is frequently exposed by the drawing down of the water. I also omit reference to objections due to certain other causes, such as the use of a stream below a sewer outlet as a source of water supply, or for manufacturing purposes, etc., since these considerations, though of great importance in many cases, do not appear to be included in the information which you desire me to present, which relates to the effect produced upon the waters of the various streams and ponds by different quantities of sewage in proportion to the quantity of water.

It will be noted, from the statement of the conditions at the different places, that in several cases the water of streams polluted by the sewage of a city or town is, or has been until recently, used for drinking at some place below the point of pollution; and obviously in such cases it is not possible to detect the presence of sewage by the appearance, odor or taste of the water or other physical means at the point where the water is drawn.

The waters of the Connecticut River, which were recently used as a source of auxiliary water supply by Hartford, do not show any evidence to the senses of the pollution they receive after the sewage has entered the river at Holyoke, Chicopee, Springfield or West Springfield, excepting floating matters, chiefly from manufacturing wastes.

The waters of the Merrimack River, though receiving a great quantity of sewage from the cities on the stream and its tributaries above Lowell, were used directly, until 1895, for the water supply of that city, and a connection is still maintained with the river for use in case of emergencies. Above Lawrence, after receiving the additional sewage and manufacturing waste from Lowell, this river was used, until 1893, as the direct source of water supply of the city; and a connection is maintained here also with the river, though all of the water supplied to

the city since the year mentioned has been filtered. Below Lawrence and below Haverhill, aside from floating matters which come largely from manufacturing wastes, the river is not offensive or objectionable in appearance.

The Housatonic River above Dalton receives considerable pollution, and much manufacturing waste from paper mills is discharged into it at Dalton. Aside from floating matters discharged, chiefly in manufacturing wastes, the presence of sewage is not evident from the appearance or odor of the water in the pond below the sewer outlet.

The waters of the Quaboag River below Palmer and the Chicopee River below Ludlow show no evidence noticeable to the senses of the presence of sewage after it has entered the streams.

The waters of the Miller's River below Athol and below Orange show no marked evidence of the sewage discharged into them at those places.

The discharge of sewage into the Chicopee River at Chicopee Falls and Chicopee has not caused objection excepting in the case of a sewer at Chicopee Falls, which discharged below a dam over which no water flowed during much of the time in dry weather; and the objectionable condition was remedied by the construction of a sewer to discharge the sewage into the mill pond above the dam.

The Westfield River, which receives the sewage of Westfield, has been used recently as an emergency source of water supply by West Springfield, the next town below.

At Ware the river receives a great quantity of manufacturing wastes both above the town and at the town itself, in addition to the sewage it receives; but its waters are not objectionable in appearance or odor after the sewage has mingled with the waters of the stream.

The French River at Webster receives an enormous quantity of manufacturing wastes from the large woollen mills at that place, which have a noticeable effect on the stream, so that the effect of the sewage alone is not determinable.

Objection has been made to the discharge of sewage into the Taunton River on account of the danger of injury to shell-fish in the stream below the sewer outlet; but the testimony recently presented by people living below the outlet shows that, with the present discharge of sewage, objectionable conditions are not created in the stream.

Much of the sewage which formerly discharged into the Mill River at Taunton has been diverted so that the quantity indicated in the table is much less than the quantity that has been discharged into the stream within a few years. The portion of the stream considered is that which lies above a large mill pond in the upper part of the city, which receives much sewage.

The Fort River at Amherst flows through a nearly uninhabited country, and it does not appear that objection has been made to the discharge of sewage at this place, or that objectionable conditions have existed excepting in the neighborhood of the sewer outlet.

The Green River at Greenfield has been objectionable to those living in the neighborhood of the mill pond below the sewer outlets at a time when the mill pond was drawn down and a large portion of the bottom exposed.

The Manhan River below the mouth of Broad Brook in Easthampton and the water in the "Ox-bow" show no evidence to the senses of the sewage discharged from the town of Easthampton into a mill pond on Broad Brook, one of its tributaries.

The pond on the Ten Mile River below Attleborough is used as a source of ice supply, and the stream itself, ten miles below Attleborough, has been used as a source of water supply, but for the last three years after filtration. Complaint has been made of objectionable con-

ditions in this stream at the upper sewer outlet at times when the water is held back by the dam above.

The condition of the Seven Mile River below Spencer was objectionable before the purification works for Spencer sewage were put in operation, partly on account of the sewage and also on account of gas wastes. The river was used as a direct source of water supply after passing through Quaboag Pond, about 6.5 miles below the Spencer sewer outlet.

The Hoosick River below North Adams gives evidence of the great pollution which it receives for a long distance down stream, and the same is true of the remaining places in the table, except Broad Brook at Easthampton, where the conditions are less objectionable than at the other places.

Omitting reference to objections caused by the manner of discharge of sewage and objections which may be due to certain other circumstances already indicated, and considering only the question as to whether objectionable conditions exist in the various streams into which sewage is discharged by reason of the quantity of sewage discharged, an examination of all the information available from the investigations that have been made shows that, where the flow of a stream exceeds 6 cubic feet per second per 1,000 persons discharging sewage, objectionable conditions are unlikely to result; and where the sewage discharges into a large pond the indications are that objectionable conditions would not result even with a considerably smaller volume of water. The only exception which has been found is at Webster, where the stream is rendered objectionable by great quantities of waste from one of the largest woollen mills in New England.

In cases where the flow or quantity of water available for the dilution of sewage amounts to from 6 to about 3.5 cubic feet per second, objectionable conditions may or may not exist; where the flow is less than about 3.5 cubic feet per second, objectionable conditions are generally found.

In the special report of the State Board of Health of 1890, Part I., p. 789, a table is given showing the amounts of ammonia, dissolved solids and chlorine added to streams by domestic sewage for various ratios of population to quantity of water flowing; and regarding this table the following statement is made, on p. 791: —

"It will be seen that the foregoing data are insufficient for reaching a definite conclusion, and a further study of the subject is very much needed. In the mean time, however, it is necessary to solve practical problems, and it is therefore desirable to limit the debatable ground as far as may be justified by the observations. For this purpose two lines have been drawn across the table on p. 789, to include those ratios of population to volume, concerning which there may be doubt. These lines include volumes from 2.5 to 7.0 cubic feet per second per 1,000 persons, and free ammonia from 0.0399 to 0.1116.

"With smaller volumes of water, the pollution is so great as to be inadmissible. With larger volumes, the pollution is so small as to be clearly admissible from the stand-point of the offensiveness of the water. From other stand-points, however, such as the use of water for certain manufacturing purposes, the amount of dilution should be greater; and in a stream used for domestic water supply it cannot be said, with our present knowledge, that any degree of dilution will make the water entirely safe for use."

The information furnished by the more recent investigations thus narrows considerably the debatable ground, as stated in that report. Where the rate of dilution is less than 3.5 cubic feet per second, objectionable conditions are likely to result from the discharge of sewage into a stream; while in cases where the dilution exceeds 6.0 cubic feet

per second per 1,000 persons, objectionable conditions have not been produced. This conclusion, as already indicated, relates only to the effect produced upon a stream or body of water after the sewage has become mingled with it, and it is assumed that the water of the stream or pond receiving sewage is unaffected by other pollution. Other considerations, many of which have already been indicated, may often decide the question as to the practicability of properly disposing of sewage by discharge into a stream or body of water, wholly aside from the question as to the degree of dilution available.

Comparison of Conditions at Other Places with Proposed Basin on Charles River.

In order to compare the conditions at the various places where sewage is discharged into streams in the State with the conditions which would exist in the Charles River if the proposed basin should be constructed, a summary of the information available as to the conditions affecting the latter stream is presented.

The natural drainage area of the Charles River at the proposed dam, assuming that the dam be built about 600 feet above Craigie bridge, is 310 square miles; but, in considering the flow of the stream, allowance must be made for many conditions by which the flow is affected. The principal of these is the fact that a portion of the flow of the stream is diverted through Mother Brook into the Neponset River from a point just below Dedham. Observations upon the flow of the stream at Newton Upper Falls and at Mother Brook show that approximately one-third of the water flowing in the river above these points, in the drier portion of the year at least, passes through Mother Brook to the Neponset River.

A large portion of the water-shed, amounting to about 24 square miles, is used as a source of water supply by the city of Cambridge and the towns of Concord and Lincoln; and large storage reservoirs have been constructed to store the winter and spring flows in this portion of the water-shed for the supply of the city of Cambridge during the drier portion of the year. A portion of the water-shed of the river above Milford, at the extreme upper end, is used for the supply of Milford and Hopedale, the water supplied to Hopedale being conveyed out of the water-shed, while that used in Milford is returned to the stream.

The flow of the stream is further modified by the large quantities of water drawn from the ground within the water-shed for the water supply of several cities and towns, chiefly Dedham, Brookline, Newton, Wellesley and Waltham. A large portion of the water used by Dedham and Wellesley remains in the water-shed; but the water used by Brookline, Newton and Waltham is largely discharged into sewers, and conveyed out of the water-shed. This water is not drawn directly from the stream, however, and much of the supply of these places in summer comes doubtless from the storage in the extensive beds of gravel in which the collecting works are situated.

Taking these circumstances into consideration, and using information available as to the flow of a large portion of the stream during the six driest months of 1900, the dry-weather flow into the proposed basin would be about 72 cubic feet per second; and, including the large amount of practically clean water present in the basin at the beginning of this period, the quantity of water available for the dilution of sewage discharged into the basin would amount to a dry-weather flow of about 100 cubic feet per second in the six driest months of a very dry season, which would occur once in about twenty-five to thirty years.

The quality of the water of Charles River is indicated by numerous

analyses of water collected at various points along its course. At Milford, near the head of its water-shed, the river receives a considerable quantity of sewage, as stated elsewhere; and at Franklin, also in the upper portion of the water-shed, the river receives considerable pollution by manufacturing waste. For many miles in its course below these places, however, it receives no notable pollution; and, as it passes the Brookline and Newton pumping stations, aside from the fact that the quantity of chlorine present is slightly above the normal, neither the appearance of the stream nor the results of the chemical or bacterial analyses of the water give evidence of the pollution that it has received. In this respect it is like those rivers given in the table which are not noticeably affected by pollution discharged into the stream above the place at which the sewage of a town is discharged.

At Newton Upper Falls and at the Lower Falls the river receives manufacturing pollution from two shoddy mills, a paper mill, silk mills, a dye works and hosiery mill and other factories, together with the sewage of several hundred operatives; and the slight increase in organic matter which may be noted by comparing the analyses of samples of the river water collected from the neighborhood of the pumping station at Waltham with the analyses of samples collected from the river at the Brookline water works, as shown in the following table, is probably due largely to the pollution of the stream by these mills. Below Waltham there are several mills discharging manufacturing wastes, including two woollen mills, a bleachery, dye house, starch factories, soap works, etc., wastes from some of which are discharged into the sewers.

Averages of Chemical Analyses of Water from the Charles River opposite the Filter Gallery of the Brookline Water Works at West Roxbury, and opposite the Well of the Waltham Water Works, for Six Months, from June to November inclusive.

Opposite the Filter Gallery of the Brookline Water Works.

[Parts per 100,000.]

Year.	Color.	Residue on Evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.
		Total.	Loss on Ignition.	Free.	Albuminoid.				Nitrates.	Nitrites.		
					Total.	Dissolved.	Suspended.					
1900, . .	.56	4.96	1.60	.0018	.0252	.0229	.0023	.46	.0020	.0000	.70	1.4
1901, . .	.92	5.45	2.60	.0020	.0314	.0275	.0039	.41	.0047	.0001	.95	1.4
1902, . .	.51	5.47	2.05	.0030	.0235	.0212	.0023	.57	.0047	.0001	.65	1.6

Opposite the Well of the Waltham Water Works.

Year.	Color.	Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Hardness.
1900, . .	.52	5.93	1.68	.0064	.0282	.0259	.0023	.53	.0070	.0002	.58	1.7
1901, . .	.82	5.93	2.72	.0065	.0323	.0289	.0034	.45	.0067	.0002	.85	1.8
1902, . .	.44	6.17	1.93	.0084	.0260	.0231	.0029	.63	.0073	.0003	.59	2.0

Between the lower dam at Watertown and the proposed dam above Craigie bridge the river receives the sewage of several hundred people from sewers along Beacon Street and sewage from areas in Boston and Cambridge provided with sewers on the combined plan, at times of storm when the metropolitan and main drainage intercepting sewers are

not capable of removing the whole flow of the tributary sewers. These outlets are located at many points along both sides of the basin. The river also receives the drainage from the Old Stony Brook conduit, containing considerable pollution, and the flow from the Stony Brook and Muddy Brook valleys, including some sewage, considerable manufacturing waste and dilute sewage from storm overflows at times of storm. This polluting matter enters the water above the Fenway Pond, and the stream passes through this pond before discharging into the river.

Assuming that the total quantity of sewage represented by the various polluting matters discharged into the stream and its tributaries between Waltham and the proposed dam might be equivalent to the discharge of the sewage of 8,000 people directly into the basin at all times, I have included the Charles River in the table with the other streams.

In applying the observations made at the various places in the State where sewage is discharged into streams to the proposed Charles River basin, it is assumed that the latter will be maintained at a nearly constant level, as proposed in your communication; that the conditions as to the discharge of sewage at many places will remain as at present; and that the basin will be maintained by the flow of the stream only, without introducing harbor water, notwithstanding that the water in the basin could, with suitable arrangements at the dam, be changed in a few hours by introducing harbor water.

Referring to the table, it will be seen that the quantity of water available for the dilution of sewage discharged into the proposed Charles River basin is much in excess of the limits indicated, below which objectionable conditions may be produced by sewage pollution.

Nearly all of the streams in the table having approximately the same flow in proportion to the population discharging sewage are also polluted by manufacturing wastes, some to a less and others to a greater degree than the Charles River, and some of them receive as great a proportion of street wash at times of rain; but, excepting in the case of Webster, where the quantity of manufacturing waste is so great as to produce by itself objectionable conditions in the stream, there is no case given in the table where the flow of a stream exceeds 6 cubic feet per second per 1,000 persons in which the wastes from all causes produce objectionable conditions in the stream. The least flow in proportion to the quantity of sewage which would be included in this statement is at Taunton, where the estimated flow of the river is 6 cubic feet per second per 1,000 persons discharging sewage, and much manufacturing waste also enters this stream.

It is of importance, in applying the observations made at the various places in the State where sewage is discharged into streams to the conditions which will exist in the proposed Charles River basin, to note that the conditions under which sewage is discharged into that stream are considerably different from the conditions at most of the other places.

A large portion of the sewage entering the Charles River is discharged intermittently at times of storm through storm overflows from combined sewers or from private sewers from separate houses, at many points on both sides of the basin. The drainage from the old Stony Brook conduit is dilute at the point where it enters the basin, and the same is true of the pollution entering through Stony Brook, which is further considerably changed in character by passing through the pond in the Fenway. These conditions, judging from the experience in the other rivers in the State and the disposal of sewage into water generally, are favorable to the rapid dispersion of the sewage in the water and the prevention of objectionable conditions.

The basin which would be created by a dam at the place indicated on the Charles River would be larger in proportion to the flow of the

stream than the reservoir or pond at any of the other places indicated in the table. The conditions which are most nearly similar to those found on the Charles River are those which exist on Broad Brook at Easthampton, and to a less extent on the Ten Mile River at Attleborough. At Easthampton sewage is discharged at one point into a mill pond which receives also gas wastes and some manufacturing waste, and the water of which changes, with the dry-weather flow, once in about twenty days. A comparison of the condition of this pond with the rapidly running streams, such as the Mill River below Northampton, Monoosnock Brook below Leominster, the Nashua River below Fitchburg or the Charles River below Milford, in which the proportion of sewage to the quantity of water available for its dilution is similar, has shown that the condition of the pond at Easthampton is less objectionable to the senses than the conditions in these streams. The condition of the large mill pond on the Ten Mile River at Attleborough below the sewer outlets is also less objectionable than the conditions at places where the flow of the stream is similar.

The experience at these and other places at which sewage is discharged into a pond or slowly moving stream, such as the proposed Charles River basin, indicates that sewage discharged into such bodies of water has a less noticeable effect upon their waters than an equal quantity of sewage has upon a rapidly moving stream of equivalent volume.

In connection with public water supplies, the advantages of the storage of polluted water in large reservoirs in the removal of the effect of pollution have been recognized for many years; and the available evidence furnished by the observations of the effects of the discharge of sewage into ponds in the State indicates that, whatever effect the sewage discharged into the proposed basin may have upon its waters, the effect is likely to be less than it would be in the case of the discharge of an equal quantity of sewage into a flowing stream receiving the same quantity of water.

In the discussion of the effect of sewage upon streams, the longest period of extreme dry-weather flow has been taken, as representing the most unfavorable conditions. Periods of extreme dry-weather flow extending for six months are rare, and the best available records indicate that such a period as has been used has occurred only once within the last twenty-eight years. In streams having no large ponds the conditions caused by the discharge of sewage during shorter periods in the summer season would possibly be slightly worse than in the longer period; and these shorter periods, especially periods of from one to three months' duration, are far more common than the long period considered.

In the case of the Charles River, owing to the very large storage in the basin, the long periods of extreme dry weather would produce the most unfavorable conditions with respect to the discharge of sewage into the basin, and the short periods would be of less importance.

Judging from the effect produced by the discharge of sewage into streams and ponds at other places in the State, and the circumstances affecting the discharge of sewage into the proposed basin, the present quantity of sewage and manufacturing waste discharged at many outlets chiefly at times of storm would not make the water objectionable in appearance or odor to those living in the neighborhood of the basin or going upon it in boats.

Respectfully submitted,

X. H. GOODNOUGH.

Name of Stream.	Water-shed (Square Miles).	Estimated Dry-weather Flow (Cubic Feet per Second).	Population discharging Sewage into Stream.	Flow per 1,000 Persons discharging Sewage (Cubic Feet per Second).	Distance from Lower Sewer Outlet to Next Dam below (Miles).	Time in which Mill Pond would fill with Dry-weather Flow (Days).	Average Free and Albuminoid Ammonia in River below Sewer Outlets during Six Dry Months (Parts per 100,000). 1900. Free Ammonia.	1900. Albuminoid Ammonia.	1901. Free Ammonia.	1901. Albuminoid Ammonia.	1902. Free Ammonia.	1902. Albuminoid Ammonia.
Connecticut River above Holyoke, including Northampton and Easthampton.	8860.0	3551.0	28,500	124.5	-	-	-	-	-	-	-	-
Chicopee River at Ludlow, ...	689.0	213.6	3,000	71.2	1.0	.5	.0047	.0244	.0069	.0288	.0057	.0279
Quaboag River at Palmer, ...	211.9	72.0	1,200	60.0	3.0	.9	.0038	.0218	.0043	.0255	.0077	.0242
Connecticut River below Holyoke, including Northampton and Easthampton.	8660.0	3551.0	66,500	53.4	-	-	-	-	-	-	-	-
Connecticut River below Springfield, including cities and towns within thirty miles above.	9960.0	3984.0	135,000	29.5	7.0	-	.0098	.0250	.0061	.0190	.0062	.0180
Merrimack River below Lowell, excluding all other cities and towns.	4664.0	2285.0	95,000	24.1	10.0	1.2	.0126	.0249	.0100	.0280	.0110	.0231
Miller's River at Athol, ...	324.3	116.7	5,000	23.3	5.0	.3	-	-	-	-	.0045	.0291
Merrimack River above Lowell, including Concord, Manchester and Nashua, N. H.	4127.0	2022.0	90,000	22.5	13.0	2.3	.0068	.0215	.0060	.0208	.0056	.0163
Chicopee River at Chicopee, ...	724.5	217.3	10,000	21.7	-	-	-	-	-	-	-	-
Westfield River at Westfield, ...	512.0	138.2	8,000	17.3	6.5	.3	.0202	.0300	.0052	.0221	.0062	.0144
Miller's River at Orange, including Athol, ...	340.8	122.7	7,500	16.4	2.3	.1	.0058	.0297	.0067	.0300	.0046	.0281
Housatonic River at Dalton, ...	55.1	16.0	1,000	16.0	.1	.5	.0142	.0378	.0171	.0311	.0128	.0265
Merrimack River below Lawrence, including Lowell, .	4828.0	2363.0	160,000	14.8	-	-	.0210	.0324	.0133	.0330	.0100	.0279
Merrimack River below Haverhill, including cities and towns within thirty miles above.	4893.0	2398.0	190,000	12.6	-	-	.0311	.0335	.0140	.0348	.0226	.0333

Charles River (proposed basin),	-	100.0	8,000	12.5	-	71.0	-	-	-	-	-	-
Merrimack River below Lowell, including Concord, Manchester and Nashua, N. H.	4664.0	2285.0	185,000	12.4	10.0	1.2	.0126	.0249	.0100	.0280	.0110	.0231
Ware River at Ware,	218.0	67.6	6,500	10.4	7.5	1.2	.0066	.0321	.0082	.0300	.0071	.0348
French River at Webster,	90.9	49.1	6,000	8.2	.5	.5	.0202	.0475	.0090	.0390	.0057	.0391
Mill River at Taunton,	43.2	16.0	2,500	6.4	.5	2.6	-	-	-	-	-	-
Taunton River at Taunton,	361.0	119.6	20,000	6.0	-	-	.0205	.0286	.0293	.0275	.1902	.0363
Nemasket River at Middleborough,	60.5	15.6	3,000	5.2	.5	.5	.0114	.0239	.0062	.0258	.0136	.0219
Fort River at Amherst,	41.0	9.8	2,000	4.9	1.0	1.9	-	-	-	-	-	-
Manhan River at Easthampton,	71.4	17.8	4,000	4.4	1.0	39.3	-	-	-	-	-	-
Green River at Greenfield,	89.0	23.1	6,000	3.8	.25	.2	-	-	-	-	-	-
Seven Mile River at Spencer,*	37.8	13.2	3,500	3.8	.9	6.1	-	-	-	-	-	-
Ten Mile River at Attleborough,	25.1	9.5	3,000	3.2	1.0	9.6	.0125	.0363	.0084	.0290	.0073	.0394
Housatonic River at Pittsfield,*	167.7	55.3	18,000	3.1	7.5	5.2	.0592	.0303	.0315	.0331	.0133	.0245
Charles River at Milford,	14.1	3.9	2,000	1.9	2.8	14.1	.7123	.0764	.1419	.0451	.2118	.0658
Hoosick River at Williamstown, including North Adams,	175.5	45.6	25,000	1.8	3.7	1.5	.0433	.0547	.0400	.0520	.0069	.0307
Hoosick River at North Adams,	117.0	31.6	23,000	1.4	.6	.2	.6912	.2965	.0237	.0542	.0094	.0380
North Branch Nashua River below Leominster, including Fitchburg.	107.5	38.7	36,000	1.1	1.5	3.9	-	-	-	-	-	-
Broad Brook at Easthampton,	11.2	3.4	3,000	1.1	.75	20.5	-	-	-	-	-	-
North Branch Nashua River at Fitchburg,	63.8	25.5	28,000	.9	-	-	.1575	.0825	.0964	.0508	.1070	.0557
Mill River at Northampton,	56.0	14.6	17,500	.8	-	-	-	-	-	-	-	-
Monoosnock Brook at Leominster,	11.0	4.9	8,000	.6	-	-	-	-	-	-	-	-

* Shows conditions before works were constructed for the purification of the sewage.

Appendix No. 6.

A REPORT

UPON

CERTAIN BIOLOGICAL PROBLEMS CONNECTED WITH THE PROPOSED CHARLES RIVER DAM.

By George W. Field, Ph.D., *Instructor in Economic Biology, Massachusetts Institute of Technology.*

Boston, Nov. 27, 1902.

John R. Freeman, C.E., *Engineer to Committee on Charles River Dam.*

Dear Sir: — In order to answer as far as possible your various questions concerning the capacity of a large body of water to dispose of pollution through the activities of living forms, without causing offence, I have made the following inquiries and studies: —

Scope of Investigation.

I. A comparison of the biological conditions at present existing in the Fens basin with the conditions likely to prevail in the proposed Charles River basin.

II. A comparison of the organisms now inhabiting the Charles River estuary with those of the Charles River immediately above tide water and with those of certain other near-by bodies of fresh water, for the purpose of determining as far as possible the relations between the amount of food material and the growth of organisms in those waters, their probable relative capacity for assimilating the expected amount of pollution, and the probability of trouble arising from excessive growths of organisms in the proposed Charles River basin.

III. A comparison of the proposed Charles River basin with basins having approximately similar conditions.

IV. The practicability of disposing, by means of living organisms, of the amount of pollution likely to enter the proposed basin, and of establishing in the basin a biological equilibrium.

V. The effects of the admission of harbor water upon the plants and animals likely to occur in the proposed basin.

VI. A discussion of the relative merits, from the biological point of view, of a brackish or fresh-water basin, under the conditions existing or likely to exist in the proposed Charles River basin.

Finally, I have undertaken to weigh all the biological evidence obtained and to form an opinion as to the superiority or inferiority of the proposed Charles River basin to the Fens basin, and an opinion upon the relative advantages of keeping the proposed basin exclusively a fresh-water basin, and of frequently or rarely admitting salt water for purposes of dilution or for flushing out.

The time has been short and the warmest weather was past before I was able to begin the work, but I believe that the data obtained, together with the facts previously known, justify the following conclusions: —

Conclusions briefly stated.

1. The Fens basin, owing to the fact that it presents conditions very different from those that would obtain in the proposed basin, provided the latter is of fresh water, affords, in my opinion, no fair or proper standard by which to judge the proposed Charles basin.

2. Fresh water, under the conditions found in the Fens and in the Charles, will be better adapted for receiving sewage without causing offensive deposits or offensive odors than are either salt or brackish water.

3. Assuming: (1) that the total flow of the Charles, in March, April, or the spring months of greatest flow, in a year of minimum rainfall is sufficient in volume to refill the proposed Charles basin on an average of once each week; (2) that in summer the flow will be sufficient to refill the proposed basin at least once in 100 days with fairly clean upland water of the quality that I have found coming over the Watertown dam; and (3) that an amount of sewage enters intermittently equivalent to the continuous discharge of the ordinary sewage of 10,000 population, — a fresh-water basin offers, in my opinion, less likelihood of bad odors or offensive conditions than a salt-water basin, and it appears to me highly probable that it can assimilate the assumed amount of sewage, together with the present, and probably the ordinary future, amount of street wash, without causing offence.

4. It further appears to me that the occasional introduction of salt water into the proposed fresh-water basin is something which should be avoided, even if it were to be frequently withdrawn at rather regular intervals, and replaced by new oxygen-bearing water from the harbor. The reason for this is that the resulting plasmolysis* would probably cause the death of the delicate fresh-water organisms that would come into contact with this salt water, and also because its greater weight would tend to hold this salt water at the bottom, and vertical circulation would be interfered with, so that it could obtain little if any fresh oxygen from the surface, with the result that the well-known phenomena of putrefaction would follow.

For the reason that the Fens basin, a small and sluggish body of nearly salt water adjoining the Charles River, and receiving the polluted flow of Stony Brook, has been claimed to present conditions somewhat similar to those that might prevail in the proposed Charles River basin, my first step was to make a careful study of the present biological conditions of this basin.

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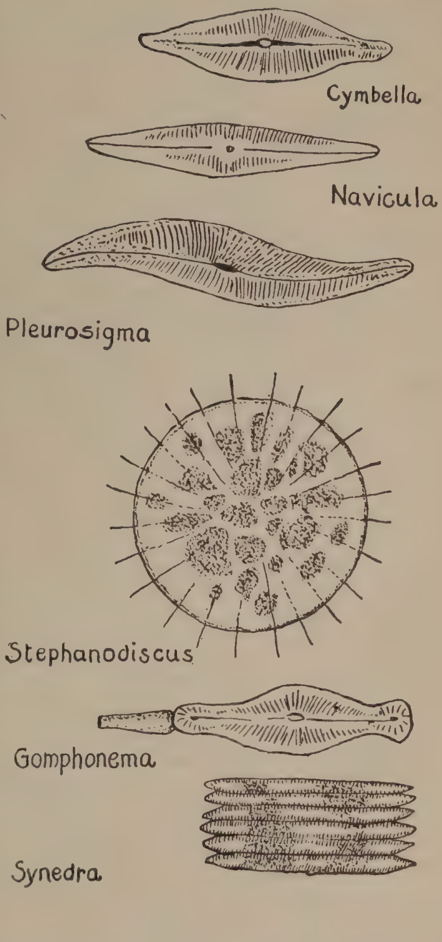
* By plasmolysis is meant a profound physical disturbance of plant or animal cells, accompanied by shrinking of the living substance, and, if extensive, by a stoppage, either temporary or permanent, of their vital activities.

I. — Comparison of Biological Conditions now prevailing in the Fens Basin with those likely to prevail in the Proposed Charles River Basin.

Present Condition of the Fens Basin. — The water and the submerged mud banks of the Fens basin are often disgustingly offensive to sight and smell. With the continuance of present conditions of pollution and the present amount and quality of flushing, these cannot fail to become increasingly prejudicial to the comfort and even the health of the inhabitants of that section as the sludge deposits become larger and deeper. Therefore, it is proper that even the remote possibility of duplicating these conditions, even in less intensity, over the much larger area of the Charles basin should be most carefully weighed and guarded; but I find that the two basins present little real similarity in those conditions that might cause anxiety.

In the Fens basin two fairly well-defined zones of life may be recognized, which zones coincide rather closely with an upper layer of fresh water and a lower layer of brackish water. The upper zone, which embraces approximately the upper two feet of water, and the mud in contact with it, supports a population of diatoms, green algæ, worms, crustaceans, snails, etc., in addition to bacteria. In number of individuals and in genera this population is very scanty when compared with those found, under more favorable conditions, in either fresh or salt water. A few amphipods hunt diligently over the surface of the upper mud among the fibres of Oscillaria, Vaucheria, the blue-green alga, Lyngbya, and among the scanty growth of diatoms (chiefly Navicula, Gomphonema, Cyclotella and Pleurosigma). Of the free-swimming



Typical Diatoms found in the Fens Basin and Charles Basin magnified about 500 diameters

life in this upper zone, the large number of small minnows is conspicuous. Their chief food, besides a considerable amount of organic débris (plant cells, etc., from the sewage and dead vegetation), consists of mosquito larvæ (Culex very abundant, Anopheles present), with a few copepods and amphipods, which also swim in this upper zone. It is of interest to note the frequency with which the minnows come to the surface for air, — a result of the comparative lack of oxygen in the water.

The lower zone of water and mud below the upper two feet just described in the submerged areas of the Fens basin, under present conditions, is not favorable to living organisms higher in the scale than bacteria, and to the unaided eye it is well-nigh a lifeless desert, more especially in the region within 1,000 feet of the entrance of Stony Brook, though under the microscope it is seen to be swarming with bacteria and a few diatoms. In the mud between high and low water live a number of small worms (Nais), but the microscopic organisms are of most importance.

COPEPOD,
MAGNIFIED 60 DIAMETERS.
TYPICAL SMALL CRUSTACEAN FOUND IN FRESH WATER ABOVE WATERTOWN DAM.
I DENOTES NATURAL SIZE.

Rate of Sedimentation in Fens Basin. — Though but a single experiment for ascertaining the rate of sedimentation furnished satisfactory data, I venture to include the results for one locality, though the figures here given must not be applied to other locations, without further investigations. On Oct. 28, 1902, in the cove near old Stony Brook gate house, a Petri dish, 92 mm. in diameter, fastened to a wire platform, was carefully placed on the surface of the mud in about 2 feet of water at low tide.

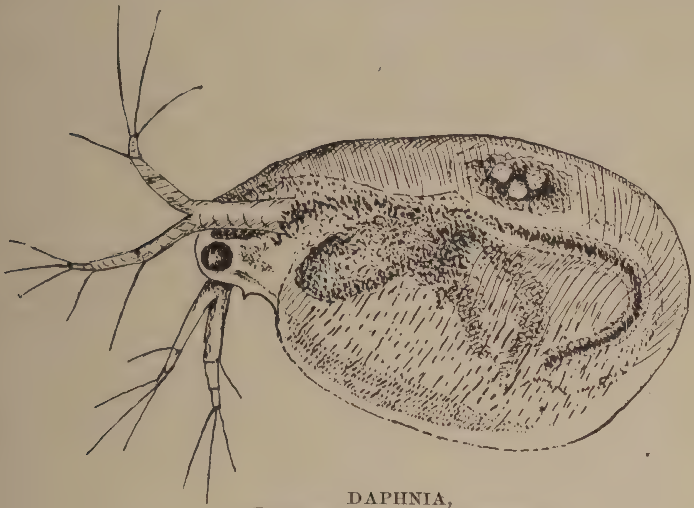
The entrance of sediment from the sides was prevented by the rim of the dish (15 mm. high), and also to some extent by the wire netting, which projected 10 mm. above the top of the rim. The total distance from the top of the rim to the surface of the mud was 30 mm. Under these conditions it is probable that the deposit found within the dish fairly represents that which settled from the column of water 2 to 3 feet high above the dish. In the 15 days (October 28 to November 12, inclusive) 7 mm. of soft, slimy mud was deposited on the bottom of the Petri dish. After drying for 25 days in the laboratory at 68° F. this mud became a compact cake, 2.5 mm. thick. Assuming that this is an average rate of deposit, the total accumulation of slimy ooze might amount to 6.7 inches in a year, equal to 2.4 inches of dry material.

Microscopical Examinations, Fens Basin Sediments and Water. — The following microscopical examinations of samples of the mud and counts of the bacteria in samples of the water were made by Mr. C-E. A. Winslow, instructor in biology at the Massachusetts Institute of Technology, whose report is as follows: —

"*A. Mud Samples.* — The mud was collected by boring with a thin

brass tube, .5 cm. in diameter, to a definite depth. (Two samples in the form of cores extending from natural surface downward were taken in each locality, one extending downwards 1.1 cm. and the other 5.9 cm. below the surface of the mud; the locations chosen for sampling were just above low-water mark.) These samples of mud were shaken up in distilled water, and the material in suspension was examined by the Sedgwick-Rafter method.

"*Series I.* — The samples of Series I. were collected on October 9, between 9 and 10 A.M. (low tide in Charles River was at 10.48 A.M.), in



DAPHNIA,
MAGNIFIED ABOUT 60 DIAMETERS.

TYPICAL SMALL CRUSTACEAN FOUND IN FRESH WATER ABOVE WATERTOWN DAM.

⊢ DENOTES NATURAL SIZE.

the immediate neighborhood of the first bridge which crosses Stony Brook after its entrance into the Fens basin, at location marked 1 on plan. All were from the flats bordering the brook. The samples as a whole appeared to consist mainly of mineral matter in a state of moderately fine division. A considerable amount of amorphous matter was also present, consisting mainly of bacterial zoöglœa, and under a high power the samples were seen to swarm with bacterial life. A small diatom, a species of Navicula, was generally distributed throughout the mud, though not in great abundance.

"The first sample, from a point just below the bridge on the east shore, contained, besides the Navicula, a scanty growth of other diatoms, Gomphonema, Cyclotella and Pleurosigma; and in its superficial layer was an appreciable growth of Oscillaria.

"The second sample, from a projecting point of flats (see 2 on plan), a short distance below, was similar in character, but contained only Navicula among the diatoms.

"The third sample, from a sheltered cove on the west side of the stream a short distance below the bridge (see 3 on plan), differed from the others in showing a considerable surface growth of Oscillaria, obvious to the eye as a green, felted layer. Diatoms were also more abundant here than elsewhere.

"The fourth sample, from above the bridge on the east bank (4 on plan), contained almost no organisms, but was richer in amorphous matter than the others. A considerable amount of vegetable tissue, cotton fibres, plant cells, etc., was present in this sample. (The masonry abutment of the bridge causes an eddy at the place from which sample 4 was taken, in which sediment is deposited in greater quantities.)

"It is apparent that the bacterial life, and the growth of algæ and diatoms vary somewhat inversely, and that at this location in the eddy near the bridge the conditions favorable to bacterial decomposition were at a maximum.

"*Series II.* — The samples of Series II. were collected on October 21, between 9 and 10 A.M. (low tide in Charles River at 11.40 A.M.), from the shores of the Fens basin in the lower part of the Fenway near the outlet of the Fens basin into the Charles River. The mud flats are but little exposed at low tide, at this part of the stream, extending not more than two or three feet from the shore at the places observed. The layer of mud here is also very thin, gravel being reached 3–4 cm. below the surface.

"The principal difference between these samples and those collected at the upper part of the Fens basin lies in the fact that they contain a much greater proportion of amorphous matter, consisting mainly of bacterial zoöglœa. The diatoms present, in both cases mostly a small Navicula, were somewhat more abundant in the samples from near the outlet, and the alga, forming a felt on the surface, was a Chlorophyte (green alga), Vaucheria, instead of a Cyanophyte (blue-green alga), as at the upper stations.

"Sample 5 was collected from a point just above the Boston & Albany track (see 5), and sample 6 from a point just above the Commonwealth Avenue bridge, both on the east shore of the stream. Samples 7 and 8 were taken from the west shore below the Commonwealth Avenue bridge, sample 7 from a point immediately below the bridge in the main stream, and sample 8 from the head of a deep cove making up into the Fens basin. All but sample 8 were from areas covered with a green, felt-like growth, but sample 8 was from an area of bare mud.

"The results show, in the first place, that the principal organisms present in the mud of the Fens basin are the bacteria, the amorphous matter consisting mainly of the growth masses, living and dead, of these organisms. As would be expected, the complex organic matter upon which the bacteria thrive, as well as the decomposition products formed by them in the absence of oxygen, are unfavorable for the development of higher plants, and we find the growth of algæ and diatoms very scanty.

"It is also noteworthy that the amount of amorphous matter is even more abundant in the lower part of the basin than near the outlet of Stony Brook.

TABLE NO. 1. — *Microscopical Analysis of Mud from Flats in Fens Basin, below Huntington Avenue.*

[Standard units in $\frac{1}{1000}$ c. c. of mud.]

ORGANISMS.	UPPER PART OF BASIN. — OCT. 9, 1902.								LOWER PART OF BASIN. — OCT. 21, 1902.							
	STATION 1 (MAP 1).		STATION 2 (MAP 2).		STATION 3 (MAP 3).		STATION 4 (MAP 4).		STATION 5 (MAP 5).		STATION 6 (MAP 6).		STATION 7 (MAP 7).		STATION 8 (MAP 8).	
	Shallow.	Deep.	Shallow.	Deep.	Shallow.	Deep.	Shallow.	Deep.	Shallow.	Deep.	Shallow.	Deep.	Shallow.	Deep.	Shallow.	Deep.
Navicula,	40	15	35	45	105	60	-	20	90	126	220	40	140	-	560	170
Synedra,	-	-	-	-	-	-	-	-	-	60	120	40	-	-	-	60
Cymbella,	-	-	-	-	-	-	-	-	50	-	-	20	10	40	-	-
Gomphonema,	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other diatoms,	5	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-
Vaucheria,	-	-	-	-	-	-	-	-	600	300	300	-	620	-	-	-
Other Chlorophyceæ,	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-
Oscillaria,	90	10	75	-	240	10	-	-	-	-	-	-	-	-	-	-
Amorphous matter,	615	360	220	570	670	560	1,020	620	1,980	3,200	6,500	3,300	12,000	2,900	11,200	1,300
Vegetable tissue,	40	-	-	30	-	-	350	-	-	-	-	-	-	-	-	-

"*B. Water Samples.* — In order to obtain a more exact knowledge of the amount of bacterial life in the various parts of the basin, a series of samples was taken on each of the three days, October 29, November 4 (between 8 and 9 A.M.) and November 8 (between 9 and 10 A.M.). Samples were taken from six stations, each representing the upper twelve or eighteen inches of the water.

"On the first day conditions were abnormal, on account of heavy rains during the few days next preceding. The other two days fell within a dry period. On the first two days a slow current was flowing to the south, under the bridge at Station 1 (Longview Avenue and Audubon Road), but on November 8 a considerably stronger current was flowing in the opposite direction. In the Charles River the tide was at the full on October 29 at the time of taking the samples, and a strong north-west wind kept the sewage from the Fens basin close to the Beacon Street embankment, so that it was obvious under the Massachusetts Avenue bridge at Station 6. On October 4 the tide was a little past low, and on November 8 it was almost dead low. The distribution of the sewage in the river was not apparent to the eye on these latter days.

"It is unsafe to draw conclusions from three series of samples alone, and it would be advisable to make more extended studies of the distribution of sewage in the Fens basin by bacteriological methods. The three examinations made, however, suggest, in the first place, that polluting material is introduced at the upper end of the Fens basin from Muddy River or Charles River or both, when the current is flowing into the basin at the Brookline Avenue gate house; and prove, in the second place, that the bacteria are extremely high in number in all parts of the basin.

"The sewage of Stony Brook introduces great pollution, and on two of the three days there was no improvement from Huntington Avenue to Beacon Street, but rather a multiplication of the micro-organisms. It is probable that the basin to the north of Stony Brook outlet is in a condition so exceedingly foul, on account of the excess of decomposing organic matter and the lack of oxygen, that the self-purification which occurs in some slow streams cannot always take place, but is at times replaced by putrefactive fermentations accompanied by an increase in the bacteria growing on the ordinary nutritive media.

"These results explain the condition of the samples of mud examined microscopically, which, as noted above, were characterized by a large amount of amorphous matter and a comparative deficiency of diatoms and algæ.

"We may conclude, therefore, that the Fens basin is more like a cesspool or a septic tank than a true river basin. The amount of organic matter which it receives is so great that the natural agencies of moving streams are incapable of dealing with it. These conditions are totally different from any which are likely to obtain in the proposed Charles River basin; and it is obviously unreasonable to draw any inference as to the nature of the proposed basin from the character of the present Fens basin."

TABLE No. 2. — *Bacterial Examination of the Water of the Fens Basin.*

[Number of Bacteria per c. c.]

STATIONS.	Oct. 29, 1902, 9 A.M. — Under Abnormal Conditions, after Heavy Rain, for which Outlet was made at Muddy River Gate.		Nov. 4, 1902, 9 A.M. — Under nearly Normal Conditions.		Nov. 8, 1902, 10 A.M.	
	On Gelatin at 20° C.	On Agar at 37° C.	On Gelatin at 20° C.	On Agar at 37° C.	On Gelatin at 20° C.	On Agar at 37° C.
I. Fens basin, near bridge at junction of Audubon Road. (See Map, Station 1.)	1,700,000	180,000	1,100,000	50,000	370,000	66,000
II. Fens basin, at bend to the north, before entrance of Stony Brook. (See Map, Station 2.)	450,000	72,000	230,000	35,000	330,000	81,000
III. Fens basin, just above entrance of Stony Brook. (See Map, Station 3.)	120,000	19,000	48,000	10,000	170,000	24,000
IV. Fens basin, at first bridge below entrance of Stony Brook. (See Map, Station 4.)	500,000	78,000	690,000	53,000	420,000	12,000
V. Fens basin at Beacon Street. (See Map, Station 5.),	750,000	100,000	1,250,000	58,000	110,000	18,000
VI. Charles River, at Massachusetts Avenue, Beacon Street shore. (See Map, Station 6.)	51,000	21,000	21,000	2,000	7,000	3,500

Observations on the Formation of Gases in the Fens Basin at and near the Outlet of Stony Brook. — Since perhaps the most obvious if not the most offensive features in the general appearance of the water of the Fens basin are the bubbles of gas and the scums, I have made some observations upon these, and have indicated their effect upon the organisms in the basin.

Gases. — On October 10, at 11.30 A.M., with bright sun and an air temperature of 52.5° F., water comparatively clear, the bubbles of gas could be seen issuing from definite, crater-like openings in the mud which covers the bottom of the basin. The number of bubbles, large and small, given out at each discharge varied from 20 to 37, and the intervals between discharges of a single crater varied from 50 seconds to 2 minutes and 20 seconds. I estimated that in the section within about 300 feet of the footbridge over Stony Brook these craters averaged about four to each square foot of area. Though on hot, sunny days, the gas produced by putrefaction might be in evidence in almost any part of the basin, these bubbles are chiefly prominent in the water about the Stony Brook outlet, and diminish in number as the distance from Stony Brook increases.

On November 15 (temperature of air 58° F., temperature of water 51° F. at surface, 52° F. at bottom, 3 feet deep) I found that the gas production had become much less, and averaged not more than one crater per square yard on the mud flats near the footbridge. No bubbles appeared in the westerly part of the stream beyond 500 feet from the bridge. Just beyond the limits of the bubbling the temperature at bottom in 6 feet of water was 49.5° F., at surface 51°. The observations on this day were confined to the section between Stony Brook and the gate at Brookline Avenue.

The offensive odor of sulphuretted hydrogen (H_2S) was conspicuous, and this poisonous gas was present in such quantities that it was fair to ascribe to it, in part, the paucity in the growth of oxygen-producing algæ, which, through their production of oxygen, tend to prevent putrefaction and its incidental offensiveness.

While in cooler weather this evolution of gas becomes less, experiments made elsewhere, together with my observations, indicate that, even in water of a temperature of 49.5° to 52° F., noteworthy activity in this evolution of gas may go on. And since this or higher temperatures are usual, at least from June to October inclusive, this rapid putrefaction and evolution of gas may be assumed to be probably continuous during these months and probably even longer.

Scums observed in the Fens Basin. — Since the scums in the Fens basin are often conspicuous, and are more or less offensive to the eye, if not to the nostrils, it is important to know their nature and origin. Microscopical examination of these scums indicates that there are two distinct types: 1st, the bacterial; 2d, the algal type. The bacterial type is the more frequent, and covers larger areas than the algal. It is derived directly from sewage and the bacteria of sewage, and after a heavy rain often contains undecomposed masses of sewage material. The second type of scums is composed chiefly of organisms higher in the scale than bacteria. It is only indirectly to be attributed to sewage-pollution, and has often a luxuriant growth of algæ for its basis. The masses of this second type of scum are often more conspicuous than the thin, transparent pellicle of the bacterial type.

The prominent kinds of scum belonging to the bacterial type are: —

(*a*) A thin, oil-like pellicle, wrinkling under the influence of the wind, and accumulating in the bays of the lee shore; this consists

almost exclusively of the gelatinous bacterial zoöglœa,* in which is entangled finely divided mineral matter, mainly street dust, which has settled on the surface.

(*b*) A similar, brownish pellicle, found under apparently identical conditions, differs from (*a*) in containing a considerable amount of blue-green algæ, and particularly a large number of diatoms of many species, all embedded in the bacterial jelly (zoöglœa).

Both of the above scums were found mixed with varying amounts of detritus from the surrounding vegetation and characteristic sewage material, such as grease, refuse fruits, semi-digested oats and hay from the streets, human fæces, a variety of grains from breweries, etc., pieces of cooked potato, seeds, broken bits of weeds, etc.

It is to these kinds of scums that Prof. Dwight Porter apparently refers: "If plant life were killed, it would be very likely to appear as a scum on the surface, which would be offensive, and then the sewage which would be discharged in through the outlets would, part of it, flow as a scum. The characteristic, I think, of sewage, especially of house sewage, is grease, which tends to flow on the surface, and I think it is that which is especially offensive." (Evidence and Arguments, 1894, page 143.)

The two most noticeable scums of the algal or non-sewage type found in the Fens basin are: —

(*a*) Most prominent of all and most offensive to the eye, although inoffensive to smell or to health, are the conspicuous felt-like patches of irregular shape and often of considerable size, green above and black below, which appear on warm, sunny days. These patches are formed by the algæ, chiefly the blue-green alga, Lyngbya, which grows as a felt of irregularly closely interlacing filaments upon the surface of the mud between tide marks. When the water covers the mud on a warm, sunny day, the gases (chiefly oxygen) generated by the active growth of the algæ remain as bubbles entangled in the meshes of the felt, and by their lifting action cause the felt to break away from the mud on the bottom and float at the surface. As it breaks away it carries with it a thin layer of mud, which constitutes the black under-surface of the green felt.

(*b*) The white or brownish froth, like soap-suds, sometimes seen floating in irregular patches during or after a strong wind; in larger ponds than the Fens basin this is often seen piled up on a lee shore, sometimes in very considerable patches. The presence in the Fens basin in large quantity of the materials that go to form this scum is shown by the quantity of this froth that forms where the water falls over the weir at the Charlesgate. Microscopical examination shows that this is a froth, having its air bubbles surrounded by a thin wall in which are embedded millions of diatom shells, some entire, but mainly in fragments.

These two latter sorts of scums formed by floating algæ are only indirectly the result of bacterial action, and, though most conspicuous and undoubtedly unpleasant from the æsthetic point of view, are usually entirely inoffensive to the smell and not prejudicial to health. But those of the former group, the bacterial or sewage type, are directly connected with the bacterial organisms of decomposition and putrefaction and, even when not mixed with floating masses of crude sewage, are offensive to sight and smell.

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* Zoöglœa is a jelly-like substance, resulting from growth of bacteria; it consists of the bodies of bacteria embedded in a gelatinous substance, a product of the fusion of the cell-walls of the constituent bacteria.

On the Effect in General of Sewage Pollution upon the Flora and Fauna of Water, and its Relation to Conditions found in the Fens.— In regard to the effect of sewage pollution upon the flora and fauna of water in general there are, so far as I know, few precise data on record. It is well known, however, that in Narragansett Bay the progressive increase of pollution has driven farther and farther down from the apex of the bay at Providence the zone within which such forms of plant life as diatoms and algæ prevail, and has replaced this former wealth of life by lower forms, chiefly putrefactive bacteria, causing conditions not very dissimilar to those now prevailing in the Fens basin. No bacterial counts or chemical analyses are available which show the degree of dilution or the average chemical constitution at the edges of these zones beyond which the diatoms, green algæ and animal life find the conditions of life too difficult for them to thrive.

This line in a general way marks the border beyond which the conditions become permanently offensive, and about all that can be said, without further research, is that such a line exists. That this delicate line, beyond which the proportion of nitrogenous matter becomes injurious to life and growth, is rather sharply defined, was indicated by a series of experiments by Vernon,* at the Naples Zoölogical Station, made with a view to improving the quality of water in the large aquaria (the prototype of those at the aquarium, Castle Garden, New York), which showed that the growth of young echinoderms (Plutei) was increased by the addition of 30 parts per 100,000 of potassium nitrite, or 105 parts per 100,000 of potassium nitrate, while larger proportions checked growth; and that the addition of 4 parts per 100,000 of ammonium chloride greatly increased the mortality.

It will be noted that these amounts which could be taken before injurious effects appeared were very large; but the products of organic decomposition, of which little is known, are probably of greater influence on life than these inorganic salts. So that at present I know of no data so useful for fixing the limits beyond which dilution becomes safe as the purely empirical data on pages 738–802 of the Massachusetts State Board of Health report of 1890, which classifies the few carefully observed facts, and reduces them to a convenient datum for comparison, without attempting to analyze causes. Since this has already served as the basis for several statements found in the evidence, we need not repeat it here.

The primary cause of the offensive conditions in the Fens is the admission of raw sewage, continuously from Stony Brook, and at irregular intervals in large quantity from sewer overflows. Raw sewage is no more immediately available for plant food or for being rendered inoffensive to our sense of smell than is the manure used by the farmer; both raw sewage and barn-yard manure must be worked upon by bacteria and their nitrogen compounds oxidized (*i.e.*, organic matter nitrified), forming ultimately nitrites and nitrates, — mineral forms which are immediately available for plant food.

It is during this "working over" of the sewage by the bacteria that the offensive odors may be evolved. With oxygen present, the work is done chiefly by the aerobic bacteria; this process is known as decomposition, and is relatively inoffensive. In the absence of oxygen, the work is done by the anaerobic bacteria; this process is known as putrefaction, and very offensive gases are liable to be given off. Of this we have an example in the Fens basin. In addition, it should be noted

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* H. M. Vernon, "The relations between marine animal and vegetable life," Mittheilungen, Zoölogical Station, Naples, Vol. XIII., 1898–99, pages 341–425.

that the aerobic bacteria are much more useful than the anaerobic in preparing nitrogenous material for plant food, and it should therefore be the effort to make conditions favorable to aerobic bacteria.

One condition of the degree of dilution required to make sewage inoffensive is that the diluting water shall have a sufficient supply of free oxygen; and the degree of dilution necessary may, therefore, in part depend upon the oxygenation of the water. Or, in other words, the measure of the amount of sewage which a given volume of water can render inoffensive depends upon the amount of oxygen in that volume of water. Water is oxygenated (1) from the air at the surface; (2) by vertical and other currents bringing the under water to the surface; (3) by living aquatic plants.

Oxygen from the Air. — The Fens basin, with its narrow winding channels and little coves sheltered from the wind by shrubbery and high banks, presents a condition unfavorable for aeration by the wind; while the proposed broad Charles River basin, with its long axis in the direction of the prevailing summer wind and subject to high waves and "white caps," presents exceptionally favorable conditions for aeration.

It has been stated, in relation to the present problems, "that putrescent matter, or matter that would be putrescent if exposed to the sun and air, when buried under 6 or 8 feet of water is usually odorless" (see evidence of 1894, page 142). This is not entirely true. The poisonous, offensive sulphuretted hydrogen found at the outlet of Stony Brook into the Fens rises and escapes, even in 6 feet of water, and the conditions that affect its generation are chiefly temperature, location, and, largely perhaps, the absence of oxygen. This absence of oxygen is connected with the lack of vertical circulation of the water.

Vertical Circulation. — A principal reason for the offensiveness caused by the amount of sewage that enters the Fens is apparently the fact that the entering sewage uses up the oxygen of the water. One reason why the water in the Fens basin, below 6 inches from the surface, is largely without free oxygen, is undoubtedly the lack of vertical circulation. It appears probable, although perhaps not fully demonstrated, that in water all fresh or all salt, wherein the difference of temperature causes almost the sole difference in specific gravity, there will be daily currents set up, somewhat analogous to the demonstrated "overturning" of the water in lakes and storage reservoirs, not exceeding about 40 feet in depth, in spring and fall. Circulation in a vertical plane may be so extremely slow as to escape direct observation, and still be an efficient aid to aeration.

The presence of vertical currents may be inferred from sundry physical and biological facts; and it is conceivable that a resultant vertical motion, so slow even as an inch per hour, might have an important bearing on the diffusion of free oxygen, of food for algæ, diatoms and microscopic life, and of the chemical products of decomposition. Had more time been available, it would have been of interest to devise experiments for clearly demonstrating the existence of these diurnal, slow, up-and-down currents, in water either all fresh or all salt, or in a thorough mixture of salt and fresh water. In the Fens this vertical motion is largely made impossible by the great difference in specific gravity of the upper and lower layers of water. By tests with the hydrometer, the fresh water of Stony Brook is found floating on top of the heavier salt water admitted from the Charles. The salt water and the fresh do not mix rapidly, and the lighter, supernatant fresh water prevents the heavy salt water from rising or circulating upwards or downwards under the influence of the daily temperature changes. It is certain that this difference in specific gravity in the Fens

basin largely, if not wholly, prevents such vertical circulation as might be caused by wind.

The Stony Brook water, coming down through the polluted pools of its underground channel, but in the Fens basin speedily spreading out over the salt waters from the Charles River, has small chance of containing free oxygen; and so the only oxygen available for preventing putrefaction in the lower layers is that which comes into the basin with the new water from the Charles through the Muddy River conduit, and that which leaks in at high tide through the Charlesgate bulkhead, supplemented by such amounts of oxygen as may be given off by the living aquatic plants.

Oxygen from Living Aquatic Plants. — In the Fens basin the population of diatoms and other algæ is not large enough to exert a noteworthy influence in the oxidation of the large amount of nitrogenous material that comes in from Stony Brook. Under ordinary circumstances, however, in either fresh or brackish water, such diatoms and algæ may exert a most important influence in helping to furnish the necessary free oxygen.

The "balanced aquarium" is a familiar example on a small scale of what is constantly taking place in nature. In such an aquarium the plants assimilate the nitrogenous material excreted by the fish and other animals, after this nitrogenous material has been oxidized, in whole or in part, by bacterial action. The plants, also, use as food the carbon dioxide, coming, mainly, from the animal respiration. In return, the plants (diatoms and algæ) give out oxygen which supplements that absorbed from the atmosphere at the surface, and thus aid to a most important extent in maintaining a continuous supply of free oxygen in the water; for, though they require a certain amount of oxygen, they liberate into the water much more oxygen than they consume.

In the days when natural conditions obtained, previous to the pollution of the waters of Stony Brook and of Muddy River, in the region of the present basin, the total number of plants and animals per c. c. was undoubtedly greater than at present. It is safe to say that the plants and animals were so adjusted to their environment that offensive conditions due to the death, decomposition or putrefaction of organic matter did not exist; the conditions represented essentially a balanced aquarium on a large scale.

The surrounding water then contained an abundance of oxygen, and the circulation of water in the large original area went on under the influence of currents and winds. With the increase of population, abnormal conditions gradually became predominant, chiefly the increasing introduction of crude sewage and the progressive encroachment upon the area of the basin, by filling; until to-day the immensely increased amount of nitrogenous matter, poured into the much-restricted basin, whose diminished area is less favorable for deriving oxygen from the air, leads to a very rapid exhaustion of the oxygen in the water, followed by putrefaction and the increase and accumulation of the products of putrefaction. This results in conditions fatal to those plants which are unable to withstand or adapt themselves to the changed conditions of life. This loss of the oxygen-producing plants reduces the capacity of the water to oxidize dead organic products, since the water is now almost entirely dependent upon the air for its supply of oxygen, instead of being able to use the supplementary supply furnished ordinarily by the diatoms and green algæ. Its capacity for absorbing sewage is thereby still further diminished. We may say that, other things being equal, the water which contains a large quantity of diatoms and green algæ can dispose of more sewage than water which contains less of these plants or none at all. Of the oxygen producers, the diatoms (see p. 317)

are notably of more importance than the other more conspicuous water plants. This being so, the conditions under which diatoms flourish are of moment. In general, diatoms multiply most rapidly in strong, diffused light; and the depth of the limit or zone of growth varies both in fresh and salt water with the color and the transparency of the water. Whipple says that: "In one reservoir, where the color was 0.86, the limit of growth was 8 feet. In another, where the color was 0.60, it was 15 feet. In colorless water the limit of growth is 25 to 50 feet or more." The turbidity of the Fens basin is unfavorable for a great growth of diatoms. The growth of diatoms depends also upon the presence of the optimum amount of food, oxygen, nitrates, etc.; this, in turn, depends upon the rate of oxygenation and nitrification, and particularly upon the vertical currents, which distribute the diatoms, the oxygen and the products of oxidation and nitrification. In the Fens basin, under present conditions, too much nitrogenous matter is introduced, in a form not immediately available for plant food; and this, together with the layer of salt water at the bottom, which, by reducing the vertical currents, interferes with the proper oxygenation of the water, leads to putrefaction and other conditions unfavorable to a sufficient growth of diatoms.

The conditions governing the growth of green algæ and the efficient role of these in aiding to maintain the purity of the water are similar to those governing the growth of the diatoms. Vernon found by experiment that 1,259 square centimeters of Ulva ("sea-lettuce," a species of green algæ, which occurs abundantly in the Charles estuary) per litre of water decreased the free ammonia from .223 mgm. to .085 mgm. after two days; to .046 mgm. after four days; and after sixteen days to .007 mgm. The organic ammonia increased in the same time from .134 to .214 mgm. The part which bacteria take in preparing the organic material to become plant food, as direct agents, and the necessity for a proper supply of oxygen, if putrefactive changes are to be avoided, has been already discussed (pp. 326, 327).

In the Fens basin, the amount of excreta from animals inhabiting the basin, *e.g.*, worms, snails, minute crustacea, insect larvæ, small fish, ducks, etc., is so small as compared with the sewage pollution that it may be neglected in the present discussion.*

Lines along which Relief is to be sought from Present Offensive Conditions in Fens Basin. — As I have indicated above, the chief conditions in the Fens basin which are inimical to aquatic life, and which lead to results offensive to sight and smell, are an excess of sewage pollution and the introduction of salt water, with its added injurious effect upon aquatic life, (*a*) through plasmolysis, (*b*) through interference with natural currents which distribute the floating plants and their food, and, by carrying oxygen from the air to the lower levels of water, retard putrefaction and the dissipation of gaseous products of putrefaction. The lines along which relief is to be sought are: —

1. To maintain as great a supply of oxygen as possible. Great care

* The exact amount of polluting material (CO_2, uric acid, urea, organic matter, etc.) which marine animals discharge has been very little investigated. For sea-urchins (*Sphærechinus* and *Strongylocentrotus*), Vernon, by the average of 12 analyses (for 100 grms. in weight of animal per litre of water per hour), found that the living animal added to the water .250 mgm. of free ammonia and .230 mgm. of organic ammonia; while an equal weight of the dead animal added about ten times that amount per hour, or 2.88 mgm. of free ammonia, and 2.04 mgm. of organic ammonia. These results are for aquaria, and can be applied to natural conditions only with caution. Yet it would seem that, if regularity of specific gravity and the necessary degree of pollution could be maintained, the Fens basin could be treated as a large aquarium, and the natural equilibrium between the plant and animal life be maintained at a proper level for rendering inoffensive the unavoidable degree of pollution. Or it may be treated as a garden, in a manner analogous to the methods of agriculture, where decaying organic refuse is changed to living vegetable matter, which in turn becomes food for animals and man.

should be taken not to exceed the limit beyond which the introduction of crude sewage or other nitrogenous matter or manufacturing wastes interferes seriously with the growth of algæ. This may be accomplished by diminishing the pollution or by increasing the dilution.

2. To avoid a frequent and extensive variation in the specific gravity of the water, which by plasmolysis may interfere with the growth of oxygen-producing plants.

3. To avoid the maintenance of strata of water of very different specific gravities, by which vertical circulation and consequent oxygenation is restricted.

4. A larger amount of the polluting material could doubtless be absorbed, if delivered at an approximately uniform rate, than is possible under the present irregularity of the sewer overflows.

Comparison of the Proposed Charles River Basin with the Fens Basin. — The conditions in the proposed Charles basin will be so different from those now existing in the Fens basin that little actual similarity will exist. The superiority of conditions in the proposed Charles basin would consist especially in the extensive surface area favorable to deep stirring and rapid oxygenation by the wind, for it lies in a direction giving maximum effect to the prevailing winds; the many times greater dilution of the entering sewage and its thorough mixture with the diluting water; the great number of oxygen-producing algæ, which increases the capacity of the water to dispose of polluting nitrogenous material; and, finally, if maintained as an exclusively fresh-water basin, the absence of a sluggish or stagnant layer of salt water at the bottom. This layer, on account of its lack of oxygen, tends to promote putrefaction of the nitrogen-containing material in the mud, with the incidental offensive odors and with conditions inimical to aquatic life.

In the proposed basin the favorable conditions mentioned above would obviously be lessened by the introduction of salt water in such a way that this heavier water might lie as a stagnant layer upon the bottom of the basin, after its manner in the present Fens basin.

II. — Some Notes on the Organisms inhabiting the Charles River Estuary, and a Comparison with Those of Certain Near-by Bodies of Fresh Water.

A Comparison of the Microscopic Plants and Animals. — Inasmuch as the microscopic organisms, on account of their great numbers, are of much importance, both as agents in the assimilation of polluting nitrogenous material and as possible direct sources of offensiveness if appearing in excessive quantities, I here introduce some tables which show the relative number of such organisms existing in the Charles River estuary, in the upland Charles River, in certain reservoirs (Spot Pond in Stoneham and Fresh Pond in Cambridge) where conditions have been made favorable for the storage of potable water, and in certain lakes (Lake Cochituate and Mystic Lake) which, of those whose statistics are available, seem most nearly in their natural state.

While perhaps open to criticism on account of the small number of samples, it is believed that a larger number would only more strongly establish the following points: —

1. The number of individuals and the number of genera of plants and animals represented is the smallest in the water of the Charles estuary and upland Charles River, larger in the potable water stored in specially prepared reservoirs, but largest of all in the natural fresh water ponds and lakes.

2. While it is true that pollution of the water by nitrogenous substances directly promotes the growth of aquatic plants, these same plants do much to justify their existence by producing oxygen (and thus tending to check putrefaction) and by assimilating the nitrified polluting material. Therefore, if pollution cannot be avoided, the presence of organisms in the polluted water may be beneficial, since they tend to increase the capacity of the water to assimilate polluting nitrogenous material without offence. In any case, it is probable that proper precautions may avoid the likelihood of an excessive growth of algæ which, in dying, might become offensive.

TABLE NO. 3. — *Results of Microscopical Examination of Brackish and Fresh Waters.*

	From the Charles River Estuary at Boston.		From the Upland Charles River.			Reservoirs prepared for Storage of Water.		Reservoirs under approximately Natural Conditions.	
	From beneath Harvard Bridge.	From beneath Cambridge Bridge.	Opposite the Brookline Filter Gallery at West Roxbury.	Opposite Norumbega Park.	Just above dam at Waltham.	Spot Pond, Stoneham, Mass.	Fresh Pond, Cambridge, Mass.	Lake Cochituate.	Mystic Lake, Oct., 1897.
Diatoms: —									
Asterionella,	-	-	-	-	5	84	8	270	-
Cyclotella,	-	-	-	-	-	1	-	51	200
Fragilaria,	-	-	-	-	-	-	-	-	-
Melosira,	-	-	-	-	-	-	13	-	-
Navicula,	2	2	1	1	2	1	-	-	-
Stephanodiscus,	35	42	-	-	-	-	-	-	-
Synedra,	-	-	4	2	3	1	1	1	2,000
Tabellaria,	-	-	-	-	2	79	32	41	-
Other diatoms,	-	3	-	-	-	-	-	-	-
Blue-green algæ: —									
Anabæna,	-	-	-	-	-	-	114	7	-
Aphanizomenon,	-	-	-	-	-	1	3	25	-
Chroöcoccus,	-	-	-	-	-	-	1	4	-
Clathrocystis,	-	-	-	-	-	-	-	-	-
Cœlosphærium,	-	-	-	-	-	-	29	2	-
Oscillaria,	-	-	-	-	-	1	-	-	-
Aphanocapsa,	-	-	-	-	-	-	-	1	-
Green algæ: —									
Arthrodesmus,	-	-	-	-	-	-	1	-	-
Cosmarium,	-	-	-	-	1	-	-	1	200
Desmidium,	-	-	-	-	-	2	-	-	-
Pediastrum,	-	-	-	-	-	10	-	-	-
Pandorina,	-	-	-	-	-	-	-	2	-

Camera lucida drawings, under a magnification of 500 diameters, of the typical food of the oyster, clam, mussel, barnacle, etc., consisting of diatoms and other algæ, bacteria, infusoria and microscopic fragments of vegetable and animal matter; taken from the stomach of a living oyster.

Protococcus,	-	-	4	-	-	-	-	13	2,200
Raphidium,	-	-	-	-	-	-	-	2	-
Staurastrum,	-	-	-	-	-	8	2	-	-
Scenedesmus,	-	-	-	-	-	-	-	-	800
Volvox,	-	-	-	-	-	4	-	-	-
Fungi :—									
Zoöglœa,	-	-	3	5	5	5	5	5	1,000
Infusorians :—									
Ceratium,	-	-	-	-	-	1	-	-	-
Ciliated infusorian,	-	-	2	-	-	-	-	-	1,000
Dinobryon,	-	-	-	-	66	20	-	-	200
Euglena,	-	-	2	-	-	1	-	3	-
Mallomonas,	-	-	1	-	-	-	-	-	-
Monas,	-	-	2	-	1	-	-	-	-
Synura,	-	-	1	-	-	-	-	-	-
Trachelomonas,	-	-	-	-	-	-	-	1	-
Chlamydomonas,	-	-	-	48	-	-	-	-	-
Glenodinium,	-	-	-	-	-	1	-	-	-
Worms :—									
Anurea,	-	-	-	-	1	-	-	-	-
Synchæta,	-	-	-	-	-	-	-	1	-
Total number of organisms per c. c.,	37*	44	20	56	86	220	209	430	7,600
Total genera,	2	5	10	5	9	16	11	17	8

* Nearly 95 per cent. of these organisms belonged to one genus.

Microscopical Analyses of Water from Charles River Estuary, at Boston. — All samples for these microscopical analyses were taken in October, 1902, except those from Mystic Lake, which are for October, 1897 (see Table No. 3). The two samples first described were collected by Mr. C-E. A. Winslow, October 24, between 9 and 10 A.M., about one hour before high tide, from the draw-spans of the Harvard bridge and the Cambridge bridge. In each case an average sample was obtained by letting down a weighted bottle from the surface to the bottom. The two samples were very similar in character, each containing a considerable amount of amorphous matter and an average number of diatoms, mostly a large Stephanodiscus (see figure, p. 317).

From the Upland Charles River. — A sample was taken Oct. 21, 1902, from Charles River, opposite the filter gallery of the Brookline water works at West Roxbury, reported from laboratory of the State Board of Health.

I took samples at noon, October 17, from the Charles River, opposite Norumbega Park, which Mr. L. R. Sawin found to contain: total organisms, 56; total genera, 4. (More samples would undoubtedly increase the number of genera found.) Also, at 1.30 P.M., from the Charles River, at Waltham, just above the dam: total organisms, 86; total genera, 9.

The comparison of the total number of genera in the tide water of Charles River with those in the upland Charles River is of importance. It will be noted that in the tidal Charles River, at Harvard bridge and at Cambridge bridge, the number of genera is few, and consists of strong types resistant to the plasmolytic effects of the changes of density of the water. On the other hand, the comparison between the number of individuals and genera per c. c. in Fresh Pond, Cambridge, and Spot Pond, Stoneham, while somewhat more comparable, is not entirely so, for the reason that these ponds have been especially prepared to offer conditions unfavorable to growth of organisms. The number of individuals and genera per c. c. in the waters of Mystic Lake and Lake Cochituate indicate better what may be expected in a fresh-water Charles basin.

The microscopical analyses of the water of Spot Pond, Fresh Pond, Lake Cochituate and Mystic Lake are from the laboratory of the State Board of Health. It is of interest to note that the figures given (the latest available) are about the average of the last twelve years for October (average, 322) in case of Lake Cochituate, but are unusually low for Mystic Lake.

Lake Cochituate.

	Total Organisms.	Total Genera.
October, 1891,	221	18
October, 1892,	233	19
October, 1893,	191	10
October, 1894,	505	18
October, 1895,	238	11
October, 1896,	1,078	16
October, 1897,	277	13
October, 1898,	105	16
October, 1899,	205	17
October, 1900,	305	13
October, 1901,	73	10
October, 1902,	430	17
Average for October for twelve years,	322	–

Mystic Lake.

	Total Organisms.	Total Genera.
October, 1893,	102,850	9
October, 1894,	150,000	11
October, 1895,	260,900	6
October, 1896,	161,000	4
October, 1897,	7,600	8

The Role of Diatoms and Algæ.—As has been indicated above, the microscopic diatoms and algæ, on account of their abundance, play an important role in the purification of water, through assimilating the products of nitrogenous decomposition and by furnishing a considerable amount of oxygen, which is important in the oxidation of nitrogenous wastes and preparing these for assimilation by plants. In this light the running waters of the Charles River, both in the upland and in the estuary, offer conditions unfavorable for growth of algæ, while the still waters show an abundant growth; this indicates that, other things being equal, the fresh-water ponds and reservoirs can, gallon for gallon, dispose of a larger amount of pollution from nitrogenous wastes, and that the still waters of the Charles basin may be expected to produce a greater number of microscopic algæ than do the waters of the present estuary; and thereby the capacity of the water, gallon for gallon, to dispose of nitrogenous pollution will be increased.

Notes upon the Larger Organisms.

In the Fresh Water.—The waters of that portion of the upland Charles represented by the above analyses, support in addition to the diatoms and other microscopic algæ, infusoria, etc., large numbers of worms of several species, copepods, Daphnia (see pp. 318, 319), amphipods, mollusks and fish, of practically the same species as are found in Spot and Fresh ponds, and in Mystic and Cochituate lakes, or any similar body of water in this neighborhood.

In the Charles Estuary.—In general, where there has been no special direct or indirect interference by man to alter conditions of life, these have remained adjusted in equilibrium at the natural level. In the Charles River estuary, however, we see evidences of modifications as direct and indirect results of man's activities. To one walking about the flats at low tide the depth and softness of the mud is a continual and often unpleasant surprise, especially near the outfall of the sewers, where the mud is particularly soft and deep. Along the edges of the basin the bottom is tolerably firm, particularly along the inhabited shores; but it is paved with broken bottles, cans and all sorts of impedimenta of civilization, so that, apart from the odors arising from the putrefying mud, the appearance of the flats is decidedly unattractive. While this slimy mud is to a considerable extent due to the precipitated material from sewage, street wash, direct dumping of garbage, etc., and in places gives decided evidence of putrefactive changes, it supports considerable life, which, possibly like "the olive in California, grows, but would rather not." The best-known inhabitant of the mud is the long-necked clam (Mya). This is distributed wellnigh over all the area of the proposed basin, on the flats now exposed at low tide, and on the bottom which is never uncovered by

water, and flourish in the detritus about the outfalls of the sewers. A fair estimate might place the clam population on an average of one clam per square foot of surface. In general appearance the clams are rather small and black; they are dug by "South Boston clammers," and from 500 to 1,500 bushels per year from the Charles River estuary are estimated by dealers and clammers to reach the market, or be used as bait.

The mud is also inhabited by several species of worms, of which the carnivorous sea or clam worm (Nereis) is the best known, from its use as fish bait.

The oyster (Ostrea), formerly abundant, is no longer living, and, from what indications I have been able to gather, probably became extinct within twenty-five years. Their dead shells are brought up by dredging operations. Their peculiar elongated shape (see photograph, opposite this page) is the result of growth being concentrated at the upper end, as a result of their closely crowded positions in the bed, or of an attempt to keep the opening above the accumulating mud, and thus avoid being smothered. The fact that there are few signs of small "seed oysters" tends to prove that the bottom was so muddy that they found few places to "set." From the elongated shape of the shells it may be inferred that the amount of sedimentation going on in that particular region was rapid during the life of that group of oysters whose shells are now to be found in quantities in the material dredged between Harvard and Brookline bridges. This sediment need not necessarily have been sand or clay, or any material which is persistent, but it might have been flocculent organic débris, which remained but a short time and left little or no evidence, beyond its effect upon the shape of the oyster shells.

In former times the oyster may have been an important agent in keeping in check the undue growth of microscopic plants and animals. Of the present most important agents in the process, in the Charles River estuary, the acorn barnacle (Balanus) is most widely distributed and with perhaps the greatest number of individuals. The other animals of most importance are the mussel (Mytilus) and the long-necked clam (Mya). These are common, but not especially numerous as compared with localities where mussels and clams abound. Mussels are found even some distances up the sewers, on the walls below the limit of high tide; but would undoubtedly be more numerous were it not for the fact that the soft, slimy sediment covers most of the objects upon which the young affix themselves, and proves fatal by engulfing them soon after they settle. The same slimy sediment, too, is deadly to most of the young clams, which, like the young oysters and mussels, after spending a few days drifting about their world, settle down to a fixed home, a rock or sea-weed, to which they become attached by a few silk-like threads secreted by a gland in the foot. While the mussel remains thus anchored and incapable of voluntary locomotion, the clam, after a few days or weeks, cuts loose and drops into the mud to begin the mode of life in which we know it best, — an inhabitant of mud and sand.

Snails are very abundant, crawling over the slimy mud.

Of the crustacea which I noted in October, the green crab in various sizes was most conspicuous, while the shrimp (Palæmonetes) in great numbers swims about the fringe of brown, shaggy "rock-weed" (Fucus) which fringes the retaining walls of the present basin and aids in disguising broken barrels and débris of all sorts which rise above the mud.

The small, bladder-like tunicate or "sea-squirt" (Molgula manhattensis) was noted in abundance on the landing floats, even as far up as the Essex Street bridge.

Ordinary Proportions.

From Charles River
Elongated shape probably due to sediment

¼ full size

Oyster Shells.

The most agreeable object to the sight is the delicate green frond of the "sea-lettuce" (Ulva), which grows abundantly on stones, bricks and other projecting points.

In general, the greater number of the animals feed upon the microscopic algæ, and under present conditions do much to check any possible excessive growth. The chances of any offensive odors* due to such excessive growth and death of algæ are very slight.

III. — A Comparison of the Proposed Charles River Basin with Basins under Similar Conditions.

I have been asked how the proposed basin would compare, from the biological stand-point, with the Alster basin, and to draw such comparisons as possible from other similar existing basins.

I regret that I have no first-hand knowledge of the Alster basin at Hamburg, to which reference has been made as offering close parallel conditions. Unfortunately, too, I know of no other basin where the conditions approximate very closely with those of the proposed Charles River basin. The formerly existing "Cove" in Providence was rather comparable to the Fens basin, on account of the relatively large amount of pollution, and the entrance of salt water. In some basins with which I am familiar, and which present certain similarities to what the proposed Charles River basin would be if tide water were admitted, considerable trouble has ensued when the conditions of salinity and the distribution of salt water have not been kept approximately uniform. Of those basins where similar conditions obtain, Lago Fusaro and Lago Lucrino, near Naples, are smaller than the proposed Charles basin, and not so closely comparable as is the Point Judith Pond, Rhode Island, which, though of nearly twice the area of the proposed Charles basin, is, in certain particulars, a rather close parallel.

While in each of these basins offensive putrefactive conditions, with liberation of sulphuretted hydrogen, marsh gas, etc., have occurred at irregular intervals, the offensiveness has been primarily due not to the death and decay of the oysters, but to conditions induced by the varying density of the water, and the deficiency in the supply of oxygen in the water, — conditions of which the Fens basin presents, to-day, but an aggravated type.

Point Judith Pond is the estuary of the Saugatucket River, draining about 18 square miles. It lies near the eastern end of the southern coast of Rhode Island, and contains about 1,500 acres. It is separated from Narragansett Bay by the rocky promontory of Point Judith, and was doubtless once a broad-mouthed bay, extending northward from the ocean. Since recent geological times this bay has been cut off from the ocean by a beach of sand on shingle, driven eastward by the currents and thrown up by the waves. In many places this beach (comparable to a dam) has become heightened into sand dunes.

It is locally believed that until the great gale of 1869 there was probably always an opening between the estuary and the ocean. This opening is said to have been navigable prior to that storm for vessels drawing at least six feet of water. Since that time this opening, locally spoken of as the "breachway" or "breach," has been frequently closed by sand, moved from west to east by tides, currents and winds. The shore, between the estuary and the ocean, is rapidly increasing in area and in height. When the "breachway" is closed, the fresh

* The odors arising from dead marine algæ are the characteristic "salt or sea breezes" which are ordinarily agreeable; while similar odors from fresh-water algæ, *e.g.*, Anabæna, Clathrocystis, etc., cause the peculiar "pondy" smells which are commonly characterized as disagreeable.

water from the upland river accumulates until it reaches a height sufficient to burst through the sand beach, then for a time a comparatively small volume of ocean water surges in and out with the tide, until the gradual accumulation of sand again closes the passage. This process is repeated at intervals, the frequency of which depends largely upon the amount of rainfall; but at the time of my investigations the growth of the beach in width and height was plainly causing the complete closure of the "breachway" at more frequent intervals and for longer periods than in earlier years.

The Point Judith basin is particularly rich in organic life. This is due to the warmth of its water and its connection with ocean water which is warmer and richer in organisms than the ocean water north of Cape Cod. There is a small amount of pollution from the sewage and street wash of Wakefield, R. I., a manufacturing village with 2,000 inhabitants, with no sewerage system, but containing extensive woollen mills, from which the ordinary proportion of grease from scouring of wool, privy drainage, etc., enters the stream.

The conditions of irregularity in the degree of salinity, of lack of oxygenation of the water, and of the rapid sedimentation, arising in the Point Judith Pond as a direct result of closure of the "breachway," led to the generation of considerable amounts of sulphuretted hydrogen, and other products of putrefaction which made the pond offensive, and proved disastrous to certain forms of life, particularly to the oysters.

The writer had occasion to study the biology of Point Judith Pond under a variety of conditions from 1896 to 1900, when, as biologist of the Rhode Island Agricultural Experiment Station, he ascertained the cause of the death of the oysters, and recommended the maintenance of a permanent and ample opening to the ocean, which recommendations have been carried out. The results of making this opening have been extremely satisfactory to the inhabitants.

Applying this experience to the proposed Charles basin, we found, in the Point Judith Pond, that: —

1. The condition of varying salinity arising from a complete dam and a basin into which fresh water was entering constantly, with salt water introduced at irregular intervals, was harmful.

2. The differing specific gravity (fresh water on top and brackish or salt water below) was accompanied by imperfect oxygenation of the water.

3. The varying salinity and resultant plasmolysis, together with defective oxygenation, were followed by death and putrefaction of organisms in the basin.

4. Restoring a more constant salinity, with its more constant specific gravity, removed the offensive conditions and renewed the growth of organisms.

Beyond these four points, comparison with the Charles fails, because the conditions of degree of pollution, relative volume of fresh water, requirements for profitable oyster culture, and lack of necessity for covering polluted sludge banks were essentially different from those to be met in the present problem, and therefore do not by analogy call for a constant salt-water basin in the Charles.

The poverty of marine life in the Charles River estuary is very striking to one familiar with the much greater abundance of genera, species and individuals in the waters of similar estuaries, even but a few miles farther south, on the other side of Cape Cod. The cause for this is found chiefly in the proximity of the cold Labrador current, and the sharp easterly deflection of the gulf stream, resulting in relatively much colder water during the summer months. Such a basin as the

proposed Charles basin could assimilate a considerably greater quantity of nitrogenous pollution if the temperature were even 5 or 10 degrees higher than that of the water of the present estuary; and a fresh-water basin would certainly be somewhat warmer in summer.

IV. — On the Practicability of establishing a Biological Equilibrium, and rendering Inoffensive, by Means of Living Organisms, the Amount of Pollution which it is stated may enter the Proposed Basin.

The Establishment of Biological Equilibrium. — The lines which must be followed in hastening such a biological equilibrium as, after a time, comes to exist under natural conditions in ponds, lakes, rivers, estuaries, etc., and, in general, in waters unaffected by human agencies, are those involved in the establishment of "balanced aquaria," where the chemical intake and outgo of the aquatic plants and animals are, within narrow limits, equal. This equilibrium may be established at almost any level desired. The quantity of plant life should be in proper ratio to the amount of plant food in solution, and the quantity of animal life should bear the proper ratio to the quantity of plant life. But I know of no data for determining just what quantity of algæ must be introduced to balance the excreta from a given weight of fish or other animal life. Such a balance is readily obtainable by actual experiment in case of aquaria where the addition or subtraction of small quantities of plant or animal life is simple. But, without more knowledge on the subject, it is somewhat rash to introduce either plants or animals into a river or reservoir without a knowledge of whether a rapid and excessive growth may not follow, with possible attendant damage, such as, *e.g.*, has arisen from the introduction of the "water hyacinth" into the St. John's River, Florida.

Danger from Excessive Growths of Algæ. — In general, we know that, if the stored water contains the decomposition products of organic matter in some relatively stable form, *e.g.*, carbon dioxide, nitrates, etc., and if these could be kept indefinitely in such a stable form, the problem of preventing the deterioration of water with its possible offensive results would be comparatively simple, both in reservoirs of potable water and in the proposed Charles River basin. But such conditions are impossible under any method known at present, and as a consequence there is a remotely possible danger from an excessive growth of algæ, which, by the production of characteristic essential vegetable oils, or as a result of death and decay, may become odorous or unsightly. Such a condition is extremely improbable, if natural conditions exist, but may be guarded against: (1) by excluding, so far as expedient, all possible sources of pollution, and so far as possible making the pollution regular rather than intermittent; (2) by furnishing, so far as possible, conditions favorable for the growth of animals, *e.g.*, copepods, Daphnia, mollusks, herbivorous fishes, etc., which, in the proper quantities, are usually most efficient in their work of browsing down the excessive growth of algæ, and unobjectionable in their methods.

The Maintenance of Biological Equilibrium. — If physical conditions are favorable, the equilibrium will become adjusted at such a level as will provide for assimilating the organic material which, in process of breaking down, may be found in the water. In case of slight variations in the amounts of this organic débris, the growth of plants and animals will reciprocally adjust itself to maintain the equilibrium at the successive new levels. Should the entrance of organic material be in extremely irregular quantities, as, *e.g.*, in the present Fens basin,

considerable time will be necessary, even if other conditions are favorable, for the algæ to adjust themselves to the new conditions. Of course a much longer time will be necessary if the quantity of organic nitrogenous débris should be so excessive as to be fatal to plant life. Just as by experiment in a "balanced aquarium" the amount of vegetation necessary to balance an excess of plant food could be added, so in the Charles River basin, under the proposed conditions, a growth of algæ would soon become established sufficient to care for such polluting organic material as now comes over the Watertown dam or is likely to enter with the street wash.

V. — The Effect of the Admission of Harbor Water to the Proposed Basin.

In general terms, the effects will depend upon regularity of distribution rather than upon quantity.

Adaptability of Organisms to Conditions. — There is abundant evidence that in nature plants and animals become gradually accustomed to conditions which would prove fatal under ordinary circumstances. Certain crustacea, found normally in fresh or slightly saline waters, have become adapted to the extreme salinity of certain salt lakes (*e.g.*, the brine shrimp of Great Salt Lake, Utah). Delicate algæ have in a similar way become capable of withstanding such a degree of heat or of salinity, or other departure from the normal conditions, as would immediately prove fatal to individuals unaccustomed to these changed conditions. In this process, regularity is of extreme importance. In the region of the proposed Charles River basin, the organisms present are practically only those which can withstand a certain degree of change, — a degree, be it noted, of very considerable regularity. The results of a series of observations, extending over at least one entire year, upon the amplitude of the variation in the specific gravity of the water in the Charles estuary, are not available; but Mr. H. W. Clark's quantitative determinations of the chlorine indicate that the greatest variation occurs at the upper end of the proposed basin, and that here, between July and October, the specific gravity of the water at the bottom varied within the limits of 1.0185 and 1.022. It is probable that the freshet flows over the Watertown dam cause a still wider variation. Those species which could not withstand as much change as now exists have been exterminated; *e.g.*, certain delicate algæ, mollusks, star-fish, etc., and those now present have become acclimated to the rather regular conditions of the specific gravity and the degree of pollution of the water.

The Effects of Changed Conditions. — If the population should become like that of ordinary fresh-water reservoirs, the introduction of even small amounts of salt water would make trouble; though the direct effect upon the organisms themselves might be slight, the indirect effects would be more prominent, and by diminishing the number of organisms and by probable interference with currents, would lessen, to some slight extent at least, the capacity of the basin to take care of polluting organic material.

Since regularity of conditions is important, both to plants and animals, the effect of the introduction of harbor water would be expected to be greater according as the intervals between the periods of introduction are increased, for the reason that the varying amount of rainfall in these intervals would affect the salinity of the water. Regular quantities, at brief, regular intervals, say once every twenty-four hours, or in such quantities at such intervals as would constitute essentially a

brackish-water basin, giving water of a specific gravity, *e.g.*, 1.012 to 1.020 (considering ocean water 1.026), would produce but a slight effect, and one, too, which would be withstood by many species of animals, among which are the clam (Mya), the mussel (Mytilus), the acorn barnacle (Balanus), the shrimp (Palæmonetes), the sea worm (Nereis); and, of the sea-weeds, many diatoms, the "sea lettuce" (Ulva), and probably, also, the prominent brown "rock-weed" (Fucus) which now fringes the estuary.

If the intervals should be increased to one week, immensely greater variation in the specific gravity might follow, but possibly with little change in the saltness of the bottom water; possibly some species would not be able to withstand this change; how many would thus succumb is difficult to say, but a heavy mortality would not be expected, and offensive conditions would not be anticipated.

With intervals of a month, the number of plants and animals which would be affected would be still greater, and very considerable interference with life would ensue, though offensiveness would scarcely be expected, even from the death of most of the population. The immediate effect might be that the water, on account of the scarcity of organisms present, would become less capable of caring for the inevitable pollution which may always be present. Such a condition would approximate most nearly to that which now obtains in the present Fens basin of any likely to be considered for the proposed Charles River basin.

In general, it is to be expected that the introduction of sea water at stated intervals, say of several days, irrespective of the amount of rainfall, would be prejudicial to the delicate organic life, on account of the irregularity of the degree of salinity; while the introduction of salt water at such intervals as may from time to time be necessary to maintain a definite degree of salinity would have little effect upon the organisms present, beyond the fact that the introduction of any salt water might result in conditions distinctly less favorable to the assimilation of polluting material than if the water was continually and entirely fresh.

VI. — Discussion of the Relative Merits, from the Biological Point of View, of a Brackish or Fresh-water Basin, under Conditions existing in the Charles River.

This involves special consideration of the relative weight of certain questions which have already been discussed, such as: —

1. Whether the liability of offensive conditions arising from excessive growth of plant life would be greater in the fresh than in the brackish water basin.

2. The effect upon aquatic life of the introduction of salt water, on account of its plasmolyzing action, and the possible tendency to interfere with the vertical currents.

3. The role of organic life in assimilating nitrogenous polluting material, and the value of numbers of individuals and genera.

4. The relative capacity of fresh and brackish water to respond quickly to irregular conditions of pollution, by rapid growth of sufficient organisms to assimilate this polluting material.

5. The fact indicated by my special experiments, that, under identical conditions, sewage introduced into fresh water was less offensive than when introduced into water from the Charles estuary or the harbor. I have made a few experiments in which, under identical conditions, I mingled 20 per cent. crude sewage, taken from the Dartmouth Street sewer at 4 P.M., with 80 per cent. (*a*) water from Boston harbor, (*b*) water from the Charles River estuary as it now is, and (*c*) city

water as now supplied in Boston; thus roughly approximating the stated ratio of polluted Stony Brook to the volume of salt water from the Charles used in flushing the Fens, but making a more strongly polluted mixture, because Stony Brook water is but very dilute sewage. The results were as follows: —

At the end of sixteen hours no odor was to be detected in the mixture of sewage and city water, while a decided odor was evident in both the harbor and the Charles River water. After twenty-two hours the odors from the Charles and the harbor waters were more pronounced than the odor from the fresh water, and continued so, until at the end of the sixth day, in a fairly constant temperature of 68° F., the odors in all the three jars had become slight; bacterial growth had practically ceased, and the water had become clear. At the end of the ninth day the sediment over about one-half the area in the jar of harbor water had become black, and covered with closely packed colonies (estimated at about two hundred) of the fungus Crenothrix, while the mud in the jar of Charles River water contained but thirty scattered colonies of Crenothrix, each surrounded by an area where the mud had turned black, and assumed the characteristic appearance of the black mud of the Charles estuary and of the harbor. No colonies of Crenothrix nor any blackening of the sediment appeared in the jar of fresh water.

In favor of a brackish-water basin appears most distinctly the possibility that, if offensive conditions should arise, the entire contents of the basin might be quickly removed, and replaced by water which, though somewhat polluted, might yet be in better condition than that within the basin. Under such brackish-water conditions, if properly handled, there is no possibility of an excessive growth of algæ which might become offensive. On the other hand, the probability is strong that in a fresh-water basin an equilibrium would soon become established between the plants and the herbivorous animals, copepods, Daphnia, mollusks, fishes, etc., which would prevent an excessive growth of algæ, so that the necessity of flushing out the basin is a contingency which is only remotely probable. But more than that, in my opinion, the introduction of any amount of sea water diminishes to a corresponding degree the capacity of the water to dispose of polluting material, for the reason that some of the more delicate algæ will be killed, thereby diminishing the oxygen production in the water. In addition, too, if the salt water is in sufficient quantity and should become a relatively stagnant layer of heavier salt water at the bottom, the tendency to putrefaction, with the characteristic odors, especially when in contact with silt containing organic matter, will be increased. Such dangers are at a minimum in fresh-water basins, for the reason that the vertical currents bring down the oxygen from the surface, and in addition carry up the products of decomposition, so that these products often escape gradually into the air at the surface, instead of accumulating until bubbles of gas form.

While the small or large number of organisms is commonly regarded as but evidence and in a sense a relative standard of the purity or the pollution of the water, a large number of organisms should, from a biological point of view, be regarded also as evidence that polluting material has been absorbed, and that, other things being equal, that water which contains the largest quantity of living organisms is capable of assimilating the largest quantity of nitrogenous pollution. The relatively small number of organisms in the waters of the Charles estuary, as compared with the fresh waters of ponds and reservoirs, indicates that a fresh-water basin could dispose of more nitrogenous polluting material than the present estuary.

Inasmuch as the additional pollution comes largely with the storm water, there will be considerable irregularity in the amounts to be assimilated, and it is of importance that this pollution should be disposed of as rapidly as possible. In my opinion, the higher temperature, the regular distribution of organisms and of food by the natural currents of the fresh-water basin, the general uniformity of conditions, the larger number of genera and individuals, particularly of the microscopic algæ and of the minute copepods, Daphnia, etc., make it probable that a sudden inflow of polluting material would be disposed of in a shorter time and with less offensiveness by fresh water than by brackish water.

And finally, the evidence that sewage is absorbed by fresh water with less offence than by the salt waters, and that the sediment in such fresh water is also less offensive than that in the salt waters, points decidedly in favor of fresh-water conditions. I am, therefore, in view of all these facts, led to conclude that, under the conditions assumed as likely to obtain in the Charles estuary, the proposed basin, with constant controlled level, would be more satisfactory than the present tidal area; and that an entirely fresh-water basin would be preferable to one either partly or entirely salt.

Very respectfully yours,

GEORGE W. FIELD.

Appendix No. 7.

GEOLOGIST'S REPORT.

A Study of the Geology of the Charles River Estuary

AND

THE FORMATION OF BOSTON HARBOR.

By W. O. Crosby.

This study was made in order to answer certain questions propounded by J. R. Freeman, engineer, with special reference to the probable effect of the proposed dam near Craigie bridge upon the shoaling of the harbor, and also in order to learn more about the character of the deep substrata at the proposed dam site in relation to furnishing an impervious and unyielding foundation for the dam, the locks and the sluices.

It is proposed to indicate at the outset, in a brief summary, in popular terms, the scope and chief results of this inquiry, before undertaking a detailed and systematic presentation of the facts, and the arguments and conclusions based upon them.

These facts and the deductions will be found set forth further on with much fullness of detail, in accordance with the request of the engineer, and in order that others may have convenient opportunity to judge of the character of the data and the soundness of the conclusions.

Scope.

The scope of the investigation was intended to cover the geological history of the present harbor and its channels, in order to learn how far these channels had their origin in tidal scour, and how far the reported conclusions of forty years ago regarding the origin and preservation of these channels is in accord with the teachings of modern geology.

It was also desired that all recorded borings in the vicinity of the proposed dam site should be studied from the geological point of view, in order to learn about the character of the ground on which the proposed dam, with its heavy masonry lock and sluices, would have to be built.

Practical Conclusions in Brief.

1. I find the conditions of firmness and imperviousness of the deep substrata of earth are probably very favorable at the proposed dam site near the Craigie bridge, and that while the bed rock is beyond convenient reach, it is probably covered by hardpan or bowlder clay, so compacted by the tremendous and long-continued pressure of the ice sheet that it is rock-like. This in turn is covered by a stiff, blue clay, and the whole is well adapted to afford a tight, unyielding foundation for lock, sluices and dam.

As I have shown on the map, the gorge of the ancient channel does not lie beneath this dam site, and the ledge, although beyond reach, is here nearer the surface than at points now farther up stream.

2. A study of the geological history makes it certain that the main channels of Boston harbor did not originate from the scour of the tidal waters, but are valleys eroded by the rivers in the broad, deep deposit of blue clay laid down near the close of the glacial epoch, when the land was higher than now and since submerged during the slow subsidence of all this district, which submergence is proved to have taken place by many facts, some of which will be later described.

The surging back and forth of the tide has probably done more to shoal these channels than it has to deepen them.

Geological History in Brief.

Changes in Elevation. — During the long past, throughout all of this region, the relative elevations of the land and sea have often changed as the earth's crust has slowly yielded and bent under compressive and other strains. An uplift of some 3,000 feet probably immediately preceded the glacial epoch, and was one of its causes. This increased the erosive power of the streams, and they cut deep gorges in the bed rock. At the close of the ice age the land subsided to approximately its preglacial level; and that there have been slow minor changes of level since the melting of the ice cap is indicated in many ways. There is good evidence within the historic period tending to prove that a part of the New Jersey coast is now sinking at the rate of about 2 feet in a century; and it is probable that the coastal region near Boston is also sinking, but at a somewhat slower rate.

The sinking and partial submergence of the land since the glacial period is shown by the yellowed, oxidized condition of the upper surface of broad areas of bowlder clay and blue clay, now 10, 20 and even 30 feet below low tide and covered by silt, which proves conclusively that they were once above sea level and exposed to the air. The slowness of the sinking is shown by areas of peat interstratified with the deposit of silt, concerning which more will be said later.

Changes in River Channels. — In a large measure the deposits of drift and sediments left by the ice sheet obscured or obliterated the preglacial topography and displaced the drainage, the ancient river courses being, in many cases, far outside of the present water ways.

There is excellent evidence to show that the preglacial course of the Charles was not, as now, around the north end of Boston, but that it formed a tributary of the preglacial Merrimac, which at that time did not turn to the east, as now, near Lowell, but continued in its southeasterly course until it entered the Boston basin and received the Charles, and the united streams ran directly across what are now the

Back Bay and South End districts of Boston (Boston Neck and Dorchester Neck) to Old Harbor.

The bed rock floor of this ancient channel is now at least 200 feet below sea level; and this buried valley is not only direct and deep, but narrow, — essentially a gorge, due to the erosive action of the river during the strong elevation of the land at the beginning of the great ice age.

For present purposes our history may begin with the deposition of the geologic formations now deeply underlying and surrounding the harbor and the estuary. These deposits may be broadly classified in popular terms, proceeding from the bed rock upward and in the order of age, into the bed rock, the bowlder clay, the blue clay and the silt or silty sands.

The Bed Rock. — The bed rock, deeply cracked by temperature changes and by the distortions of the earth's crust, superficially weathered and worn, and deeply furrowed through millions of years by the preglacial streams, had been scraped clean by the long-continued, slow, grinding advance of the continental glacier seaward.

The bed rock, although nowhere exposed in this part of the Charles valley, is known by many borings and excavations to be chiefly slate, and to be deeply buried at most points beneath the drift deposits. I have collected information in regard to borings, for wells, foundations, plunger elevators, etc., and, from a study of these in connection with other data, have outlined the contours of the bed rock on the accompanying map.

The Bowlder Clay. — The melting of the ice sheet at the close of the glacial epoch, which the glacialists have good reason for believing happened not more than ten thousand years ago, left upon the surface of the bed rock a considerable thickness of bowlder clay, which is in large part massed in the form of drumlins, of which Beacon Hill is a large and composite example.

This bowlder clay, or "hardpan," known also to geologists as "till" or "ground moraine," is the unwashed, unsorted and unstratified portion of the glacial drift coming from, and deposited at the final melting of, the ice sheet. It is found chiefly on the higher portions of the bed rock, and its absence in the deeper valleys indicates that the ice continued to push forward in these valleys after it had become stagnant on the uplands.

The Blue Clay. — This differs radically from the bowlder clay, being a stratified deposit of the fine clay particles and the finely pulverized quartz, brought down in the turbid waters while the continental ice cap was melting, and deposited in the quiet waters of the glacial lake, some 10 miles in diameter (Lake Shawmut), formed by the waters of the Charles, the Mystic and other streams flowing eastward and impounded within a projecting lobe of the ice sheet that stretched down from the north into what is now Massachusetts Bay. That the waters of this lake reached an elevation of about 70 feet above the present sea level is shown by the delta plains of sand and gravel. By the subsequent uncovering of lower outlets during the gradual recession of the ice, its elevation was reduced to 40, and then to 20, feet. The blue clay was deposited in the deeper and more tranquil parts of the lake, in horizontal layers, until it finally attained a level about 5 feet above the present level of the sea.

The construction of the East Boston tunnel has afforded excellent opportunities to examine this clay; and that it is a true glacial deposit

is proved by the angular stones of all sizes sprinkled through it, and by the complete absence of shells and other fossils.

Erosion of Valleys in the Blue Clay. — On the drainage of Lake Shawmut, by the farther recession of the ice, the clay deposit, which was still at a considerable elevation above the sea, was exposed to the air long enough (hundreds, if not thousands, of years) to permit the Charles and other streams to erode broad valleys in it, 50 feet or more in maximum depth.

That the erosion of the clay, producing all the depressions now occupied by the inner harbor, was subaerial and not marine, — fluvial and not tidal, — and that it extended over a long time, are indicated by the superficial yellowing of the clay through the oxidizing influence of the atmosphere. This is an important point, since *it proves conclusively that the estuary of the Charles is not due to tidal scour, but is the product of the erosion of the blue clay plain, by the meandering rivers, at a time when the land stood higher relatively to the sea than now.*

The Silt. — During the subsequent slow subsidence of the land the deepening of the valleys ceased, and, instead of being further degraded, they were somewhat aggraded by the deposition of sand and fine gravel to varying depths; and with the farther subsidence, carrying these deposits below low-tide level, the sand and gravel gradually gave way to the silt, or black, carbonaceous, sandy mud, or muddy sand, which everywhere forms the immediate floor of the harbor below low-water mark.

This relatively thin deposit, commonly 2 to 5 feet, except where it has attained greater thickness in levelling up holes and gulleys, which shows in its carbonaceous character the absence of oxidizing conditions during and since its accumulation, and which shows by its loose and uncompacted structure that it has never been covered by any later deposit, is very generally fossiliferous, containing a great abundance and variety of shells.

That its rate of deposition has been extremely slow is proved by the fact that it has witnessed a notable climatic change, for it contains certain species of shells no longer living in Boston harbor or north of Cape Cod.

It is probably entirely within bounds to say that the deposition of the silt has covered a period of five thousand years, the rate varying, according to the locality, from less than 1 foot to 5 feet in a thousand years. That a slow subsidence of the land has taken place meanwhile is shown by the silt being found at many places covered by or interstratified with peat, which is now below sea level.

The various channels of the harbor and the estuaries leading inland from them are essentially drowned valleys, and deposition at an appreciable rate is going on only in the vicinity of areas of active erosion such as are afforded by some of the shores of the harbor more exposed to waves in severe storms. These shores, especially in the inner harbor, are now very generally protected by sea walls, wharves or other structures. Similarly, the numerous dams on the Charles River must effectually cut off whatever contributions of sediment the river itself might make to the estuary. Hence it would seem that deposition must be almost at a standstill, except as material already deposited may be shifted from place to place with variations of the currents. For the silting up of the inner harbor, or that part of the harbor inside of Castle and Governor's islands, there is, then, excepting the relatively small volume of sewage wastes and wharf sweepings, no important available source of material except the silt in the outer harbor or that now resting in

the inner basins, and especially in the estuaries of the Charles and Mystic.

Although the silt is loose and easily transported, the inefficiency, under existing conditions, of the tidal scour or movement of the tidal prism as regards the movement of the silt is seen in the fact that practically no part of the harbor is free from it, except where it has been removed by dredging. In other words, *the tide in the harbor proper is nowhere strong enough to sweep away the silt and erode the underlying deposits (gravel, sand, clay or bowlder clay).*

Without a doubt, the wasting away of the harbor islands, following their deforesting, which wasting went on rapidly within recent years until prevented by the embankment walls, has furnished very much more material for shoaling the harbor during the past fifty or one hundred years than the silt that has come down the rivers; and the strong beginning of the flood tide, helped by strong waves driving in from outside, has scattered this material.

The slow contribution of silt by the upland water is well illustrated by the depth and contours of the lower Mystic Pond, 75 to 80 feet deep, — an old kettle-hole, left by the melting of a huge buried fragment of ice, which is to-day deeper than Boston harbor anywhere inside of Deer Island light.

The upland Charles is a sluggish stream, not silt bearing, and for a hundred years has been well provided with sedimentation basins in the form of millponds, the one at Waltham being particularly large, and well adapted to arrest the further motion of any silt.

Sources for Silting up of Harbor. — The only possible sources for material with which the harbor above Governor's Island can be shoaled are: first, the present silt deposits, which might perhaps be moved to some small extent from one point to another; second, the wash from the islands and headlands, now nearly stopped by the sea walls; and third, the waste products of a large commercial and manufacturing population.

With this last source restrained, no source remains that can cause material harm.

The Geological Data considered in Detail.

The Bed Rock.

The preceding summary shows that the geological data having a bearing upon the problems presented by the proposed dam across the tidal portion of the Charles River are chiefly those relating to the glacial and postglacial periods in the history of the river. The underlying bed rock, largely of a slaty character, is in general, and especially for points near the modern river, so deeply buried beneath the glacial and later deposits as to be without appreciable direct influence in determining surface features and conditions. Under the general processes of glacial and preglacial erosion, however, the character and structure of the bed rock have undoubtedly determined in a large degree the contours and trend of the bed rock valley; but these are reflected in the surface topography only in a very broad and general fashion, and chiefly indirectly, determining the accumulation or massing of the glacial drift or bowlder clay in which the relief features of this part of the valley are now mainly expressed. It appears, therefore, that, notwithstanding its unobtrusive character, the bed rock is still a factor in this problem, and the natural starting-point of our investigation.

Character and Structure of the Bed Rock.

Many borings and excavations, supplemented by an occasional outcrop toward the head of the estuary, suffice to show that the concealed bed rock floor of this part of the Charles River valley is mainly slate, of similar character to that so well exposed in the Somerville ledges and quarries, with probably, as in Somerville, an occasional dike of diabase (trap).

The general structure of this district is indicated in the geological colors on the accompanying map. The main features, beginning on the south, are: —

First. — A broad band of conglomerate, trending east-west through Newton, Brookline, Roxbury and Dorchester to the harbor at Savin Hill. The structure of this belt of conglomerate is anticlinal, the beds dipping northward on the north side and southward on the south side, and passing in both directions beneath the overlying slate formation, which once arched completely over and concealed the conglomerate. Not only has erosion cut through the slate and deeply into the conglomerate, but to the westward, in Newton and Needham, it has also cut through the conglomerate, exposing the ancient volcanic rocks — melaphyr and felsite — which here form the floor of the Boston basin. As it approaches the sea this broad arch of conglomerate narrows rapidly, the axis subsiding in this direction; but it probably extends at least as far east as Thompson's Island before it is completely covered by the slate. This anticlinal belt of conglomerate lies about midway between the northern and southern borders of the Boston basin, — the northern highlands (culminating in Arlington Heights) and the Blue Hills, — and is at once the central and dominant arch or structural feature of the basin, determining, by its superior resistance to erosion as compared with the softer bordering slates, a topographic division of the basin into two broad longitudinal valleys, — the Charles and the Neponset.

Second. — Each of these main valleys is divided longitudinally by a subordinate belt of conglomerate and volcanic rock. That on the north, in which alone we are now interested, extends through Newton and Brighton, south of the Boston & Albany Railroad, but seems to die out in Brookline before reaching the Back Bay district of Boston, the belt of slate separating it from the main central belt of conglomerate widening rapidly eastward from the vicinity of Chestnut Hill Reservoir, as the map clearly shows.

Third. — In the hills north of the Charles River, in Watertown, another, but very subordinate, anticlinal ridge of conglomerate rises through the slate. But with this exception, the entire area between the conglomerate of the Newton and Brighton ridge and the granitic rocks of the northern highlands, expanding eastward to embrace Belmont, Cambridge and Somerville, is underlain, so far as known, by slate, which, in the longitude of Boston proper, is probably continuous from Arlington Heights to the northern boundary of Dorchester and the southern shores of South Bay and Old Harbor.

Fourth. — Below Riverside the course of the Charles River is wholly confined to the southern part of the broad, northern slate area, where the structure is clearly synclinal, the topographic valley coinciding with a geologic valley. The trend of this slate syncline, conforming with the Newton and Brighton anticline, is first to the north-north-east, parallel with the western border of the basin, nearly to Waltham, and then, to the eastward, as far as Cambridgeport and the eastern end of the


BED ROCK CONTOURS
—OF—
BOSTON HARBOR
—AND—
CHARLES RIVER VALLEY
—BY—
W. O. CROSBY, GEOLOGIST.
AS DEDUCED FROM A STUDY OF OUTCROPS, DRUMLINS
AND SUNDRY DEEP BORINGS
DEC. 10, 1902.
GEOLOGICAL STRUCTURE SHOWN BY FOLLOWING COLORS
YELLOW Granite and Crystalline Rocks. RED Felsite
GREEN Melaphyr. BLUE Conglomerates.
BROWN Slate WHITE Water surfaces at present time.
Courses of pre-glacial streams
Drumlins.
Bed-rock Contours
Datum Boston City Base
The dotted Bed-rock Contours are those determined with less certainty than the full lines
Outcrops of Bed-rock.
PRESENT TOPOGRAPHY
Contours at 20, 60, 100 etc feet above sea level
Streams Railroads
SCALE (Original 1: 30000)
Geological structure at A, B and C rendered uncertain by accumulation of drift
East Lexington
Malden
West Medford
Medford
Arlington
Arlington Heights
Revere
Revere Beach
Mt. Washington
Everett
Wellington
Somerville
Chelsea
Beachmont
Orient Heights
Winthrop Highlands
Winthrop Center
Winthrop Head
Charlestown
East Boston
Cambridge
Watertown
Waverly
Waltham
Prospectville
Allston
Brighton
Newton
Newtonville
West Newton
Auburndale
Newton Center
Newton Lower Falls
Newton Highlands
Newton Upper Falls
Brookline
Thompsonville
Jamaica Plain
South Boston
Charles River
Bird Island Flats
Apple Island
Point Shirley
Deer Island
Governors Island
DEER ISLAND LIGHT
Green Island
The Graves
Calf Island
Outer Brewster
Middle Brewster
Great Brewster
BOSTON LIGHT
LONG ISLAND LIGHT
Lovells Island
Gallops Island
Georges Island
Spectacle Island
Long Island
Rainsford Island
Thompson Island
Savin Hill
Moon Island
Squantum
Peddocks Island
Hull
Point Allerton
Nantasket Beach
Roslindale
West Roxbury
Mt. Hope
Wellington Hill
Atlantic
Needham
Highlandville
105600
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
5000
20 MILES
19
18
17
16
15
14
13
12
11
10 MILES
9
8
7
6
5
4
3
2
1 MILE
52800
10 MILES
1 MILE

nticline, where, probably, it is deflected toward a south-easterly course .. conformity with the ledges of Somerville and Governor's Island. Having once reached this trough of relatively soft rocks, the river has followed it to the sea, and continues to follow it, with some obvious meanders and digressions, in spite of the deep drift deposits which now encumber and obscure its bed rock valley.

Topography of the Bed Rock.

The main facts to be noted under this head are graphically expressed on the accompanying map, entitled "Bed Rock Contours," which, in addition to the modern hydrography, shows: —

First. — The actual outcrops of the bed rock, the character of the outcrop (whether conglomerate or slate, etc.) being readily determined in each case by reference to overlying colors.

Second. — The drumlins or special accumulations of bowlder clay, which are usually based upon ledges or indicate relatively elevated portions of the bed rock surface, and embrace nearly all the bowlder clay of this area not covered by modified drift (sand and gravel).

Third. — Contour lines for the bed rock surface, based upon all these facts, and especially upon all the deep borings and excavations of which I have been able to obtain a definite record, a systematic and detailed list of these data being appended to this report.

Fourth. — The probable axes or deepest lines of the principal bed rock valleys.

Fifth. — The surface contours for elevations of 20, 60 and 100 feet above and 20 feet below sea level.

It will be noted that the distribution of the drumlins is in harmony with that of the rock outcrops, the two classes of facts co-operating to determine the outline of the bed rock valleys; and it will be further noted that the bed rock contours, based chiefly, as stated, upon the borings, are yet in harmony with both the natural outcrops and the drumlins.

We thus discover not only that the bed rock valley of the Charles River follows approximately the modern course of that stream below Riverside, and that both are in substantial harmony with the geologic structure; but also that it is joined, between Brighton and Cambridge, by a still deeper and broader valley from the northward, which is readily identified as a direct southward continuation of the valley of the Mystic River where it cuts through the northern highlands and enters the Boston basin.

The highland section of the valley of the Mystic is, in size, out of all proportion to the diminutive stream which now poses as its architect; and, as I have elsewhere shown,* it is highly probable that we have here the preglacial channel of the Merrimac River, which followed the general course of the Middlesex canal from the great bend at North Chelmsford to West Medford, whence, instead of bending abruptly to the eastward, as does the modern Mystic, it continued in the same general direction across Cambridge to its confluence with the Charles, this part of its course being approximately marked now by the basins of Spy and Fresh ponds, and being further attested by the deep boring near the outlet of Fresh Pond, which reached bed rock at a depth of 148 feet, or about 130 feet below mean sea level.

The Charles thus appears as a preglacial western tributary of the preglacial Merrimac; and the course of the united streams, or of the Merrimac after receiving the waters of the Charles, was clearly not that of the

* "Technology Quarterly," vol. 12, p. 302.

modern Charles around the north end of Boston, but directly across the Back Bay and the South End districts of Boston (Boston Neck and Dorchester Neck) to Old Harbor.

It is extremely probable, as will appear more clearly later, that the slate ledges of Somerville are continued as more or less distinct ridges underlying Charlestown and the north end of Boston. These ridges are doubtless more or less irregular and discontinuous; but there seems to be no reason to doubt that they should be regarded as an effectual bar to the view that the preglacial drainage of the Charles River valley followed the course of the modern river below Harvard bridge.

On the other hand, as the contours so clearly indicate, the far more direct southern course is free and unobstructed to a depth of 200 feet or more. The southern border of this valley is quite well defined by the outcropping ledges in Brighton, Roxbury and Dorchester, and the northern border also by less prominent ledges in South Boston. Reviewing the borings, we find that beneath Cambridgeport the bed rock is from 110 to at least 150 feet below sea level, rising toward the north; across the Back Bay and South End districts of Boston, several borings, as shown by the list, have reached the bed rock at depths of 140 to 170, and even 200 feet; and a boring near the northern shore of the Calf Pasture in Dorchester, and presumably on the southern slope of the valley, reached bed rock at a depth of 166 feet; while at the pumping station of the main drainage system, at Old Harbor Point, bed rock was reached at a depth of 214 feet, or 204 feet below low tide. It is apparent that from West Medford the preglacial Merrimac held its southward course across the Boston basin until it was joined by the Charles near the east end of the Newton and Brighton anticlinal band of the harder rocks; and that from this point the course was more southeasterly, but still crossing the strike of the slate beds, until it met the north side of the great Brookline and Savin Hill arch of conglomerate, which deflected it to the eastward, the seaward course of the buried channel being probably to the north of Thompson's and Spectacle islands, and thence seaward via Presidents Roads and Broad Sound.*

Continuing the general view of the bed rock topography, as interpreted in the contour lines of the map, and recalling that the normal bed rock for the entire district north of the Highlands is slate similar to that of the Somerville ledges, as indicated by the map, and confirmed by all the outcrops and all the borings which have reached solid bed rock, we may note, first, that the prevailing strike of the slate, so far as determined, varies from approximately east-west near the Charles River to about north-west-south-east in the vicinity of the Mystic; and, second, that the slate, more or less steeply inclined at most points, naturally tends to form ridges trending with the strike, with of course intervening valleys, which must in general slope seaward. It has also been assumed that all parts of the bed rock surface would, if bare and elevated above sea level, exhibit free drainage; in other words, that there are in this district no true rock basins.

One of the longest and most pronounced of the bed rock ridges is indicated by the drumlins of College and Winter hills and the ledges on which they rest, Convent Hill (recently removed), Bunker and Breed's hills in Charlestown, Man-of-War Shoal (summit of a submerged drumlin), the low drumlin culminating in Maverick Square, East Boston, and the more prominent East Division drumlin, Bird Island flats (an-

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* This problem of the preglacial course of the Charles River has been ably discussed by my colleague, Mr. F. G. Clapp, "Technology Quarterly," vol. 14, p. 198.

other submerged drumlin), Governor's Island drumlin and ledge, and the flats extending a mile beyond. It is a fair assumption that a ridge of this length is composite, consisting of overlapping and more or less distinct members; and probably the lowest point is between Charlestown and East Boston, this col, descending, possibly, 100 feet below low tide and marking the head of a valley descending to the south, between Boston and East Boston. Whether simple or complex, this ridge is clearly the southern slope or wall of a deep main valley, following the present course of the Mystic below West Medford, and the product especially of the drainage of the Malden and Melrose valley. The deep borings on the north side of Charlestown (Nos. 2, 5, 6), reaching depths of —100 to —120 feet,* are doubtless in this valley, but south of its axis; while the Chelsea Ferry boring (No. 2), reaching the ledge at about —65, is well up on the north slope, and confirmed by the Government Hill drumlin; and that the true course of the valley is directly east from the mouth of the Mystic, across East Boston in the vicinity of Central Square, south of Eagle Hill, is demanded by the geological structure, and suggested by a boring which failed to reach bed rock at a depth of —100 feet on the flats between the First Division drumlin and the small drumlin of Wood Island Park. This course continued leads to a confluence with the Merrimac-Charles valley between Deer Island and Long Island.

The ledge later to be described as underlying the Warren bridge and Copp's Hill may apparently be regarded as a southern branch of the ridge just described, or, perhaps better, as a minor ridge between this and a second main ridge including, besides the ledges of Clarendon and Powder House hills, the drumlins of Spring, Central, Prospect and Asylum hills in Somerville, East Cambridge Hill, Beacon and Fort hills in Boston and the Burnham Channel ledge. The East Somerville drumlin tends to connect these two linear series of hills; and, while to the north-west of this point the ancient drainage may have been tributary, laterally through the first ridge, to the valley of Malden River, to the south-eastward it was quite certainly longitudinal, passing beneath the present bed of the Charles River between the Lowell and Warren bridges, as will be more fully shown in a later section, and thence eastward between Beacon and Copp's hills and north of Fort Hill. Some idea of the depth of this part of the valley is afforded by the fact that bed rock was not reached at —115 feet at the corner of State and Broad streets (No. 23), and only at a depth of —135 close on the north-east side of Fort Hill (No. 24). Farther east, confluence with the minor valley heading in the neighborhood of the Man-of-War Shoal appears probable, and the course is indicated by a boring with a record of —118 and no rock at Pier 4, South Boston. Beyond this the course is open to doubt, but is probably north of the Burnham Channel ledge and south of Castle Island to a confluence with the Merrimac-Charles valley between Castle and Thompson's islands.

The drumlins of North Cambridge suggest, in connection with the Spring Hill and Winter Hill drumlins and their associate ledges in Somerville, a transverse ridge or water parting; and from the south-western end of this ridge a third north-west-south-east ridge extends at least as far as the city hall, the slate bed rock on this line having been well exposed in sewer excavations (No. 2) in the campus of Harvard College, and almost continuously southward to the river. Between this area of a relatively high bed rock surface and the ledges and drumlins

* From this point on, depths and elevations are referred to Boston base or approximate low tide.

of Somerville is apparently a broad valley, the drainage of which, as indicated by the low level reached by the bed rock surface in several borings (Nos. 7–9, 12) in the lower part of Cambridgeport, probably escaped to the southward, as shown on the map, to become immediately tributary to the Merrimac-Charles valley.

Only one other bed rock ridge remains to be mentioned. This embraces the drumlins and ledges of South Boston, including the Half-tide Rock; and with greatly diminished height it appears to be continued westward under South Bay and the South End into the heart of the Back Bay district. The borings indicate that west of South Bay the elevation of the crest of the ridge varies between — 60 and — 80 to its abrupt termination, as shown by the crowded contours on the map.

North of this deeply buried western half of the South Boston ridge, between it and the high Beacon Hill section of the Somerville and Boston ridge, is a broad, deep valley, the axis of which is at least 160, and probably 200, feet or more below the Boston base. The anomalous feature of this valley is that, while it appears to merge broadly with the Merrimac-Charles valley on the west, it is, for the lower levels, closed to the eastward, as the contour lines show. It appears thus as a short, broad, deep, *retrograde* tributary of the main drainage channel of the region.

In seeking an explanation of this depression, we may profitably note the fact that some of the borings reporting bed rock in the section of Boston south and east of Beacon Hill have clearly not reached any of the hard and thoroughly solid rocks (slate, conglomerate, trap, etc.) such as make up the whole of the bed rock surface wherever it is exposed in ledges and shallow excavations; but instead the drill has passed from the glacial drift to imperfectly consolidated sands, clays, marls, etc., in part of colors unknown to the drift, and probably representing Tertiary strata underlying the drift and filling deep depressions or valleys in the harder formations or true bed rocks of the region. The artesian well of N. Ward & Co., on Spectacle Island, 560 feet deep, passed through at least 360 feet of unconsolidated material, only part of which could be regarded as glacial drift; and the deep well at the corner of High and Purchase streets in Boston, reported as reaching the bottom of the drift at about 100 feet, is in soft materials comparable with the Tertiary deposits of Martha's Vineyard and Long Island, to a depth of at least 500 feet. Following up this idea, it is a natural suggestion that during the strong elevation of the land at the close of Cretaceous time the Merrimac-Charles River, then flowing directly eastward south of Beacon Hill and Fort Point Channel, cut a deep valley in the ancient bed rocks of the region; and then during the Tertiary subsidence the lower portion at least of this valley was filled by Tertiary strata, and thus virtually obliterated; and the stream, during the succeeding elevation, chose a new course across the horizontal Tertiary plain, and parallel with the great conglomerate anticline, where during the Pleistocene (early glacial) elevation it again trenched the older bed rocks, this channel being in turn obliterated by the deposits of the glacial period; and the river, in obedience to merely fortuitous or accidental causes, adopted its present circuitous course around the north end of Boston. It would thus appear that the channel was originally directly across the city proper (Cretaceous time), and that in the later history of the river it was diverted first to the south (Tertiary and Pleistocene times) and then to the north (postglacial time).

According to this view, the anomalous retrograde bed rock valley south of Beacon Hill is the original channel partially re-excavated during the early Pleistocene elevation of the land.

Normal Profile of the Bed Rock Channel, and its Relations to the Early Glacial History of the Region.

For one important feature of the bed rock topography we are not directly dependent upon either surface observations or borings, since it is a universal feature of the major valleys of the glaciated zone, and, in a general way at least, may safely be inferred where the data fall short of a complete demonstration. The feature referred to is an inner gorge, trenching the floor of the main valley and extending into the principal tributary valleys. This gorge is in this region rather seldom indicated in the surface topography, being almost universally filled by drift deposits, and thus obliterated as a topographic feature. It has been fully demonstrated for the valley of the Nashua River by the numerous deep borings made by the Metropolitan Water Board in the vicinity of Clinton, revealing a narrow gorge some 200 feet deep, dividing the bed rock floor of this broad valley.* It is demonstrated also for the valley of the Merrimac by the deep borings of the Lowell water works, between Lowell and North Chelmsford, the gorge in this instance being about 100 feet deep, and its bottom at or below sea level; and also by the deep basin of the lower Mystic Lake, the water in which has a depth of 75 feet, and probably overlies a very considerable depth of drift.† Similar facts have been observed for many other streams; and the gorges of the larger rivers may be traced seaward for many miles, the gorge or submerged fiord of the Hudson having still an unfilled or open depth below sea bottom, as determined by soundings, of over 2,800 feet, 80 miles east of Sandy Hook.

We find the simple and sufficient, and apparently the only possible, explanation of these phenomena in a strong elevation of the land at the beginning of the great ice age; this elevation, which amounted in this latitude to at least 3,000 feet, being regarded by many glacialists as the chief cause of the continental glaciation. This continental uplift must have proved a great stimulus to the drainage, especially near the continental border; and the streams, as their fall and erosive power increased, must in general have ceased meandering and thus slowly widening their valleys, and begun to cut rapidly downward toward a new base level. Thus were developed, before the land was finally covered by the great ice sheet, a system of deep, U-shaped gorges, trenching the floors of the relatively broad and shallow preglacial valleys.

In this vicinity the borings are insufficient to define the gorges of the Charles and Merrimac valleys; and it is at least among the possibilities that none of the borings have been located on the deepest line or axis of the broad valley. Of the existence of a deep inner valley there can, however, be no question; and all the available evidence points to the general location indicated by the lowest bed rock contours on the map, and more definitely by the heavy line within these contours. A well-defined lateral gorge is clearly indicated by the borings in the valley of Stony Brook, where it cuts through the Roxbury highlands. To this inner valley or gorge and its tributaries the floor of the preglacial valley stands in the relation of a terrace; but the borings appear inadequate at most points to determine satisfactorily the normal elevation of this terrace. In the Back Bay and South End districts, however, or just where the surface features count for the least in

* "Technology Quarterly," vol. 12, p. 294.
† "Technology Quarterly," vol. 12, p. 300.

locating the gorge and determining the breadth and elevation of the bed rock terrace, the borings do help us out to some extent, showing the floor of the preglacial valley to be at least 60 feet below mean sea level.

Bed Rock Details for the Charles River Below Harvard Bridge.

The modern course of the Charles below the Harvard bridge is not only unnaturally circuitous, but the depths of the bed rock surfaces are in part much less than at points farther up stream. This evidence is presented on the map and in the list of borings, but it may be briefly summarized here: —

The 39 borings on the line of the Harvard bridge to depths ranging from —31.4 to —77.7 feet failed in every instance to reach bed rock, the entire series ending in blue clay. The deepest boring, —77.7 feet, is 100 feet from the Boston end of the bridge.

The borings for the new West Boston bridge, 64 in number, on three different lines, and varying in depth from —36.9 feet to —73.5 feet, also failed in every instance to reach bed rock. Three borings, —46.4, —46 and —51.6 feet, struck rock, marked on the profiles "stone, probably bowlder," and this interpretation is probably correct. It may be added, however, that all of these borings ended in bowlder clay, indicating that the bed rock is less deep than at the Harvard bridge.

No borings are available for the Craigie bridge, but for the first bridge of the Boston & Lowell Railroad, built in 1833, we have a full series. This bridge, which is now used for freight tracks of the Boston & Maine Railroad, crosses the river somewhat diagonally, at a mean distance of about 250 feet below the Craigie bridge. The borings, numbering 133, in two lines, the southern line being most complete, range in depth from —12 to —45.4 feet; and with a very few exceptions they all end on or in bowlder clay, although apparently no serious attempt was made to penetrate the bowlder clay or hard pan. At the Boston end of the bridge several borings in each line reached slate bed rock at depths varying from 12 to 17 feet below low tide, the depth increasing westward.

No boring data for the other railroad bridges have come to light; but for the Warren bridge we have a series of 10 borings, extending across the river; and with two exceptions they all reach bed rock, at depths ranging from —11.84 to —39.68 feet.

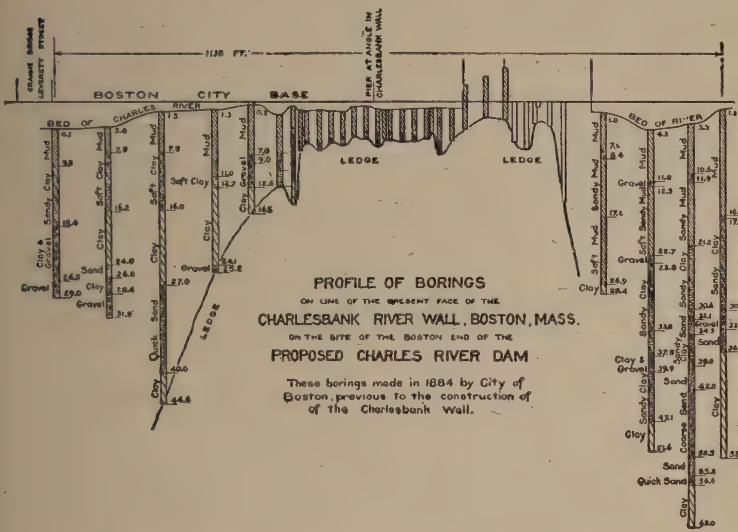
Of the 70 borings made for the new Charlestown bridge, on three different lines and to depths ranging from +4.3 feet to —58.3 feet, the deeper borings being mainly toward the Boston side of the river, only one is reported as reaching ledge, and this at a depth of only —11 feet, in Charlestown. Another boring, 175 feet nearer City Square, is marked as ending on a bowlder at a depth of —5.7 feet, and it appears highly probable that this interpretation should be applied in both cases. This appears the more necessary, since, with the exception of two borings near the Boston end of the bridge which end in blue clay, they all end in bowlder clay.

Of 55 borings made for the new dry dock at the Charlestown Navy Yard, in an area 1,300 by 700 feet, and reaching depths ranging from —33 to —104.4 feet, nine reached slate bed rock at depths varying from —39 to —98, and penetrated it 0 to 14.4 feet. A comparison of these bed rock determinations shows that they partially outline a valley deepening in a north-easterly direction.

These several series of borings clearly indicate a bed rock ridge crossing the river, the crest of the ridge being on or near the line of the Warren bridge. Apparently the only alternative is to assume that,

in the case of each of the Warren bridge borings reported as ending on rock, the rock was a bowlder, and not ledge. But, even then, such frequency of bowlders large enough to be mistaken for ledge would suggest the close proximity of the ledge.

In East Cambridge and Charlestown bed rock determinations, besides those already mentioned, are few, and none are very shallow. Two or more wells of J. P. Squire & Son on Gore Street, East Cambridge, reached bed rock at about —45; a well of the Charlestown Gas Company at Thompson Square encountered bed rock at the same depth; and it was found at a depth of —59 feet in the well of G. G. Fox, Edgeworth and Vine streets, Charlestown. Although not very shallow, these borings are clearly not deep enough to suggest their location in or near the preglacial channel of the Charles; and it may quite



safely be assumed that the drumlins of East Cambridge, Asylum Hill, Breed's Hill and Bunker Hill rest on still more elevated portions of the bed rock surface.

On the Boston side of the river borings and bed rock determinations are much more numerous, and sufficient to develop, at least approximately, the form of the bed rock surface. Starting from the Boston end of the old Boston & Lowell Railroad bridge, where, as already noted, slate bed rock was reached at depths ranging from —12 to —17 feet, we find that the bed rock surface rises southward, toward the low ridge or drumlin crossed by Leverett and Chambers streets, and that it formerly reached the level of low tide at the corner of Brighton and Lowell streets.

The borings made for the Charles River embankment, extending from Leverett Street and the Craigie bridge to Cambridge Street and the West Boston bridge, along the front of the wall, and to the number of 50, ranging in depth from —1 to —63 feet, discovered bed rock at 32 points, between 200 and 950 feet south of Craigie bridge, at depths varying from —0.8 to —44.6 feet. These bed rock determinations are so grouped (see the profile reproduced above) as to indicate a rather flat-topped ridge, from 1 to 8 feet below low tide, with fairly steep

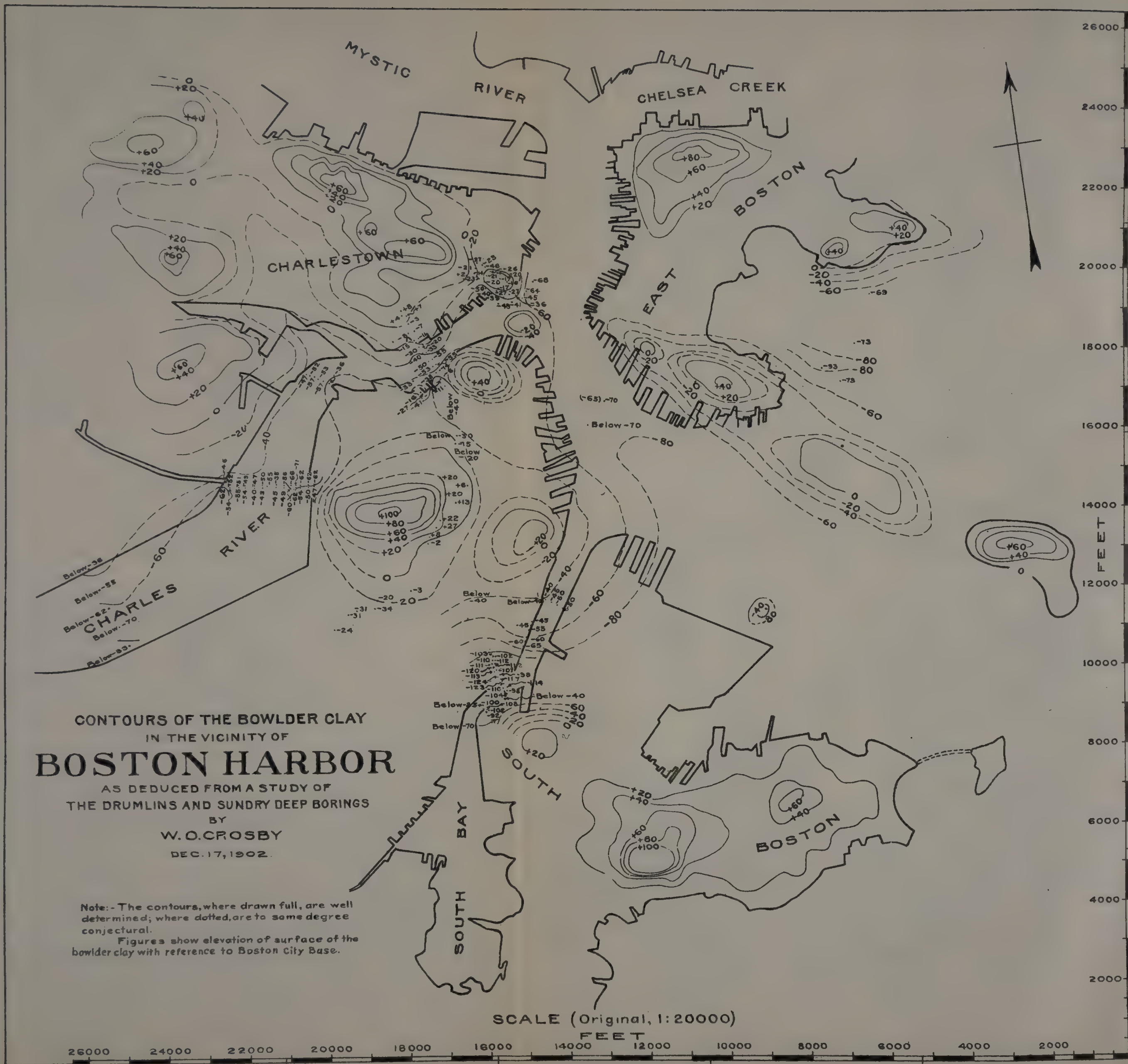
lateral slopes; clearly a north-westward continuation of the ridge on which the Chambers Street drumlin is built, and probably continuous under the river with the bed rock elevation bearing the East Cambridge drumlin.

On Charles Street, about 200 feet east of the embankment line of borings, we have a nearly parallel profile in the 22 borings, 0 to —33 feet in depth, made for the new sewer between Leverett and Cambridge streets. Of this series, 10 borings reached bed rock at depths of 0 to —13 feet within a distance of 800 feet south from Leverett Street; and continuing through Leverett and Brighton streets to Lowell Street we find 7 borings, all of which reach bed rock at depths from +8 to —10 feet. A comparison of the profiles shows the average elevation of the bed rock to be increasing eastward, although the ridge is divided on Charles Street by a valley at least fifteen feet deep.

That this ridge continues to the eastward we have abundant evidence in the fact that the sewers have also encountered ledge (slate) on Poplar Street and Kennard Avenue, and that the following houses stand on slate ledge, at elevations ranging from +15 to at least +25: Nos. 33 and 67 Poplar Street, corner of Poplar and Spring streets, corner of Milton and Spring streets, and corner of Poplar Street and Kennard Avenue. The general course of this ridge is south-easterly, with the axis of the drumlin, as shown by bed rock elevations of —15 in the wells of Fobes, Hayward & Co., on Chardon Street, and Graves & Sons, Bowker Street; —50 feet at Marston's Restaurant, on Hanover Street; —28 feet at Pemberton Building, Pemberton Square; and —15 feet, corner of Washington and Court streets. The narrowness of the ridge is proved by a bed rock elevation of —15 feet in the artesian well of the Massachusetts General Hospital, near the corner of Allen and Blossom streets.

Following the profile of the Charles Street borings southward, around the base of the main drumlin of Beacon Hill, we have 14 borings, ranging from about +1 to —14 feet in depth. Of these, 4 reached the slate bed rock in the vicinity of Pinckney Street, on the axis of the drumlin, at depths near the low-tide level (+1 to —2), and two others, between Mt. Vernon and Chestnut streets, at depths of —10 and —14 feet, approximately.

The broad valley between Beacon Hill and its dependent drumlins and the relatively small but well-defined drumlin of Copp's Hill corresponds to a bed rock valley. Of this we have abundant evidence. Thus, of the 15 borings for the new sewer, on Causeway Street between Lowell and Prince Street, reaching depths of +8 to —36 feet, only those at the intersections of Charlestown and Prince streets, and possibly only the latter, reached bed rock at elevations of +1 to +8 feet. All the other borings of this series terminated in blue clay or sand, not one of them even reaching the bowlder clay, which presumably covers the bed rock in the valleys, as well as on the ridges, though less thickly. In close proximity to the Prince Street boring is the deep artesian well of the Boston Gas Company, in which slate bed rock was reached at —35 feet. The bed rock elevation proved by the borings is probably an eastward extension of the bed rock ridge disclosed by the Warren bridge borings, and it may be assumed to continue as the axis or foundation of Copp's Hill. Between Copp's Hill and Beacon Hill we have the following additional bed rock elevations, afforded by artesian wells and borings, and proving the existence of a bed rock valley at least 75 feet deep below Boston base: Moxie Nerve Food Company, Haverhill Street, —53 feet; Schrafft & Sons, Portland Street, —65


MYSTIC
RIVER
CHELSEA CREEK
CHARLESTOWN
EAST
BOSTON
CHARLES
RIVER
SOUTH
SOUTH
BAY
SOUTH
BOSTON
CONTOURS OF THE BOWLDER CLAY
IN THE VICINITY OF
BOSTON HARBOR
AS DEDUCED FROM A STUDY OF
THE DRUMLINS AND SUNDRY DEEP BORINGS
BY
W. O. CROSBY
DEC. 17, 1902.
Note:- The contours, where drawn full, are well determined; where dotted, are to some degree conjectural.
Figures show elevation of surface of the bowlder clay with reference to Boston City Base.
SCALE (Original, 1:20000)
FEET
MILES
HELIOTYPE CO. BOSTON.

feet; Tufts old factory, Portland Street, —49 and —74 feet; Eastern Cold Storage Company, 28–44 North Street, —79 feet; Boston subway borings, between Causeway and Hanover streets, —5 to —40 feet, in clay and no rock.

The Bowlder Clay and Drumlins.

The bowlder clay or hard pan, known by geologists also as the till or ground moraine, is the unmodified (unwashed and unstratified) portion of the glacial drift, or that part of the drift deposited on the final melting of the ice sheet without being exposed to the effective sorting or modifying action of water. It rests at most points directly upon the bed rock, and in this region at least is found chiefly on the higher parts of the bed rock surface, where it is very largely massed in the form of rounded hills or drumlins. The practical *exclusion of the bowlder clay from the deeper valleys is a fact of great significance and interest, indicating that the ice continued to move along these lines after it had become stagnant on the uplands*, and suggesting comparison with a river, the chief deposits of which are not on its bed but on its flood plain.

As regards its relations to the subterranean movement of water and the stability of foundations built upon it, the bowlder clay, having been compacted by the tremendous and long-continued pressure of the ice sheet, is comparable with the underlying bed rock; and in this connection it is interesting to note the concentration of bowlder clay in the vicinity of and below the site of the proposed dam, as indicated by the drumlins and numerous borings. The main facts are expressed by the contours on the map constructed for that purpose, which show the extension of the drumlins downward below sea level, and in a general way the elevation of the surface of the bowlder clay over the interdrumlin areas. But for the area in which we are specially interested the topography of the bowlder clay is in some respects more clearly and instructively exhibited in a direct comparison of the borings.

Thus, beginning on the south-west, or over the main bed rock valley, we find that none of the Harvard bridge borings encountered the bowlder clay; although the minimum elevation reached by the borings is —77.7 feet, they all ended in blue clay, which overlies the bowlder clay. Of the numerous borings for the West Boston bridge, all reached bowlder clay at elevations ranging from —29.4 at the Boston end of the bridge, where the slope of the Beacon Hill drumlin passes beneath the river, to —66.1 at a point 300 feet farther west. From the axis of this bowlder clay valley, which is indicated on each of the three lines of borings, and slopes northward from —57.5 on the south line of borings to —66.1 on the north line, or approximately 10 feet in 100, the surface of the bowlder clay rises westward to elevations between —40 and —30 in about 300 feet, beyond which it falls off to about —50 in the next 400 to 500 feet, and then continues with a slightly undulating surface but no decided or general slopes for fully 1,000 feet, or to the Cambridge shore, where the elevations on the different lines are, from south to north, —55.35, —50.5 and —49.3. This approximately plane upper surface of the bowlder clay is undoubtedly very characteristic of the interdrumlin areas, and *probably indicative of a similar flat bed rock surface below a moderate thickness of bowlder clay.*

The Charles River embankment borings, although extending across the axis of the northern spur or member of the Beacon Hill drumlin, and ranging in depth to a maximum of —63 feet (midway between the West Boston and Craigie bridges), have all failed to reach the bowlder clay, showing apparently that the valley in the bowlder clay developed

by the West Boston bridge borings continues under the eastern margin of the river at least as far as Craigie bridge, and probably continues to deepen in that direction, since it is improbable that the embankment borings are near the axis of this trough.

The Charles Street sewer borings, following more closely the base of the drumlin, have found the bowlder clay at or near the surface at nearly all points between Beacon and Cambridge streets, although it is difficult here to distinguish original deposit from artificial filling; but between Cambridge and Leverett streets, where most of the borings not ending on the high-level bed rock attained depths of —25 to —33 feet, none have encountered typical bowlder clay, developing chiefly clay of a more or less sandy character.

The numerous borings of the original Boston & Lowell railroad bridge reached the bowlder clay in most cases, and at depths averaging much less than for the West Boston bridge borings, although again we note a surprising uniformity of depth for the main part of the profile. For the first 300 feet from the East Cambridge shore the borings were too shallow (—17 to —23 feet) to reach the bowlder clay; but for the next 250 feet it is developed at depths ranging from —23 to —33 feet. In the next 250 feet depths of —40 to —45 have ended in the blue clay, marking the position of the deep channel in the bowlder clay with depths of the bowlder clay surface probably exceeding 70 feet, if the valley continues to deepen northward. *This locates the bowlder clay channel near the middle of the river at this point*; and east of the channel the bowlder clay shows again a striking uniformity of elevation, ranging only from —31 to —35, for fully 800 feet, or to the slate ledge on which the east end of the bridge rests.

On the line of the Warren bridge two borings, 275 and 280 feet from Causeway Street, reported bowlder clay at depths of —16.3 and —27.6 feet, and 670 feet from Causeway Street at —33.3 feet. These are clearly on the north-western slope or toe of the Copp's Hill drumlin. At 918 feet from Causeway Street bowlder clay is wanting, and rock was reached at —11.8 feet. The next boring, 1,118 feet from Causeway Street and 696 feet from Water Street in Charlestown, ends in gravel at —16 feet, and the next, 576 feet from Water Street, in clay and stones (probably bowlder clay) at —32.2 feet. Beyond this we have, at 490 feet from Water Street, rock at —32.2 feet and no bowlder clay; and at 264 and 190 feet, respectively, from Water Street, rock at —12 and —15 feet, respectively, and no bowlder clay. These facts seem to prove the existence, between the Copp's Hill and Beacon Hill drumlins on one side and the Charlestown drumlins on the other, of a ledgy tract, essentially bare of drift, as is so commonly observed between well-developed drumlins above sea level; and it appears improbable that the valley in the bowlder clay, traced from the West Boston to the Craigie bridge, finds an outlet in this direction, but, if continued, it is more likely to turn to the eastward, between Beacon and Copp's hills. It is, however, quite unnecessary to regard this as an erosion or drainage channel, and if it is, its true slope or gradient may after all be to the south into the main valley.

The borings for the Charlestown bridge, connecting still more closely with the stoss slope of Copp's Hill, all ended on or in bowlder clay, proving the elevation of its upper surface to range between +13.8 feet in City Square, Charlestown, and —53 feet under the main channel, about 500 feet from Causeway Street in Boston. The three separate lines of borings agree very closely, each revealing a simple bowlder clay valley, with a short, steep slope toward Boston, rising to the surface in Causeway Street, and a long, gentle but undulating slope toward

Charlestown; and the comparison shows quite plainly that the axis of the valley descends eastward, or toward the harbor. This valley is evidently not deep enough to be regarded as a down-stream continuation of the valley noted in the profiles south of the Warren bridge; and we cannot escape the conclusion that the *Warren bridge marks the true divide for the bowlder clay as well as for the bed rock.* The probability that the southern bowlder clay channel or valley descends either to the south or to the east becomes a practical certainty; although it is perhaps most probable that it descends both ways from a divide in the vicinity of Craigie bridge, which would again bring the contours of the bowlder clay into harmony with those of the bed rock.

The Navy Yard borings all penetrate the bowlder clay, and the elevations of the surface of this deposit show again a fair degree of uniformity, although the extremes are +7 and —63, — a range of 70 feet. Four-fifths of the determinations fall between —10 and —40 feet, and over half of them between —15 and —35 feet. The contours of the bowlder clay show no regard whatever for the bed rock valley previously noted as sloping to the north-east; and over the deepest part of this valley the bowlder clay attains an extreme thickness of 85 (—13 to —98) feet. The bowlder clay contours run lowest to the south, evidently declining toward a bowlder clay valley between the Navy Yard and the Man-of-War Shoals drumlin, which may fairly be regarded as the down-stream continuation of the valley in the bowlder clay disclosed by the Charlestown bridge borings; and it may be added that the depths are entirely favorable to that view. The farther extension of this valley, assuming it to be the product of stream erosion and a true drainage channel, may be either to the north, toward the deep, preglacial valley of the Malden River, or to the east, between Copp's Hill and the East Boston drumlins, the data in hand being insufficient for the determination of this point.

Under the harbor, on the lines of the East Boston tunnel borings, the surface of the bowlder clay has a fairly uniform elevation of —80 to —90 feet, averaging a little lower in the northern or North Ferry profiles than in the southern or South Ferry and State Street profiles. The flatness or approximately plane character of the surface of the bowlder clay is quite as marked here as under the Charles River, although the actual elevation is 20 to 50 feet less. That this great depth of the bowlder clay continues and increases around the south and west sides of Copp's Hill is shown by the failure of all the East Boston tunnel borings in the State Street section to get below the blue clay, and the fact that the artesian wells on North Street found the blue clay resting directly on the slate bed rock at a depth of 104 feet.

At many points the bowlder clay is separated by a few feet of bluish (unoxidized) sand and gravel, often more or less clayey, from the blue clay, giving a gradation from the bowlder clay into the blue clay, and showing that the former was exposed somewhat to the sorting action of water at the beginning of the deposition of the latter. A feature of the bowlder clay of still more special interest is found in the interstratified beds of washed material, including gravel, sand and clay. This has been noted in some of the borings for the Charlestown bridge; and in at least ten of the Navy Yard borings the bowlder clay is divided by one and in some cases two layers of sand, varying from 1 to 5 feet in thickness, and separated by 15 to 20 feet of bowlder clay. This intercalation of limited layers of washed material in the bowlder clay is not uncommon; but it is usually confined, as in this instance, to the lee slopes of drumlins, the Navy Yard borings being directly in the lee of the Bunker Hill drumlin; and this relation is very satisfactorily

confirmed by the East Boston tunnel borings in the lee of Copp's Hill and the subway borings in the lee of Beacon Hill. This principle would exclude washed material from the bowlder clay north of Beacon Hill; and this is precisely what, with unimportant exceptions, the several bridge profiles show. The exceptions are impervious blue clay, and *no facts have come to light indicating that the bowlder clay in the vicinity of the site of the proposed dam falls below the normal as regards either firmness or impermeability.*

Glacial Lake Shawmut.

On the final disappearance of the ice sheet, it lingered longer, as previously stated, in the valleys than on the uplands, and much longer in the basin of Boston harbor and Massachusetts Bay than over the country to the westward, including the main part of the Boston basin. The eastward drainage was thus impounded, forming the glacial lake to which I have given the name of Shawmut, communicating on the south-east with glacial Lake Bouvé during the time when the latter discharged eastward into Cohasset harbor. At its highest stage the surface of Lake Shawmut was about 70 feet above the present level of the sea, the elevation being marked by extensive delta plains of sand and gravel formed by the tributary glacial streams, the courses of which are now marked, in some cases by winding ridges of gravel known as eskers. With the continued recession of the ice, successively lower outlets for the united waters of lakes Shawmut and Bouvé were opened, and we find, in consequence, eastward from the 70-foot plains, extensive delta plains at elevations of 40 and 20 feet, approximately, and extending in the south part of the Boston basin to the present shore of the harbor.

While these deposits of relatively coarse detritus, resulting from the washing of the bowlder clay or ground moraine as it was being set free by the melting of the ice, were forming in the shallow marginal portions of Lake Shawmut, adjacent to the northward-receding margin of the ice, the finer material (quartz flour and clay), once incorporated with the coarse in the composition of the bowlder clay, was being deposited in the deeper and more tranquil part of the lake, remote from the mouths of the glacial rivers. Thus was formed the important deposit known as the blue clay or glacial clay. It was laid down in regular horizontal layers, and probably completely filled the basin of Lake Shawmut up to the highest level now reached by the clay, which is about 5 to 10 feet above the present high-tide level.

The Blue Clay.

Under Boston harbor and its tributary estuaries we find above the bowlder clay, or above the bed rock where the bowlder clay is wanting, in normal order the blue clay. This, as we have seen, is a true glacial clay, a deposit of mud from the waters of the glacial lake (Lake Shawmut) which came into existence as the ice retreated from the area of Boston harbor, the land being still much more elevated than at present. This body of fresh water, free from tidal currents, and frozen over during a large part of each year, presented, in its freshness and tranquillity, conditions exceptionally favorable for the deposition of quartz flour and clay. That the blue clay is not marine is proved by the entire absence of fossils, and the fact that similar clay is not being deposited in the harbor at the present time, except perhaps to a limited extent on the eel-grass flats. It is in the main a very tough, plastic clay, but containing, as do all glacial clays, a large portion of impalpably fine

sand or quartz flour. There are, however, occasional thin streaks and layers of true sand, representing periods when there was more motion in the water.

The angular fragments and grains of rock, of all sizes up to bowlders several feet in diameter, scattered irregularly here and there through the clay, as so well shown by the East Boston tunnel, and most abundantly, as a rule, toward the bottom of the deposit, are a very characteristic and significant feature of the clay. This material could not have been borne in suspension by the same currents that deposited the clay, but it was undoubtedly dropped by floating ice, — floe ice and icebergs. Another convincing proof of the glacial origin of the blue clay is found in the fact that in a number of the East Boston tunnel borings, on the west side of the harbor, and more or less in the lee of the Copp's Hill drumlin, the clay is divided, usually near the bottom, by a sheet of bowlder clay from 10 to 25 feet in thickness. Similar phenomena have been observed elsewhere, as in the lee of the Beacon Hill drumlin, and, as previously noted, in one of the Charlestown bridge borings. Apparently this can only mean that when the deposition of the clay began in this part of the harbor the margin of the ice sheet was still near by, so that a slight readvance of the ice spread a layer of bowlder clay over a part of the blue clay; and when the ice again retreated, this intrusive sheet of bowlder clay was in its turn covered by a considerable thickness of the blue clay.

The borings show that the clay beds reach an extreme elevation of about 5 feet above high tide, which accords well with observations made in the clay pits of Everett and West Cambridge; and it extends to a depth of 80 to 90 feet below low tide in many of the East Boston tunnel borings, and to still greater depths, down to nearly 200 feet below the same datum in artesian wells and borings located in the deeper bed rock valleys. The under surface or bottom of the blue clay is in general, of course, the upper surface or top of the bowlder clay, except for the bed of sand or gravel, of no great thickness, which occasionally intervenes; and it is improbable that the maximum depth of this contact has yet been determined. There can be no doubt, however, that, since the clay must have been deposited in perfectly horizontal, even layers, and have covered the entire area to about the level of the highest point which it now attains, its maximum original thickness in the inner part of the harbor was not less than 200 feet.

On the drainage of Lake Shawmut, by the farther recession of the ice, the clay deposit, which was then still at a considerable elevation above the sea, was exposed to the air long enough (hundreds and probably thousands of years) to permit the Charles and other streams to erode valleys in it to maximum depths of 50 feet or more; and since in this harbor area the preglacial channels of the rivers had been completely effaced by the deposition of the blue clay, the new channels are more or less independent of the old, and this we have seen is markedly true of the lower or tide-water portion of the Charles. It was at this time, as the result of some relatively slight and wholly fortuitous inequality in the surface of the clay deposit or of the sand, a slight thickness of which was here and there spread over the surface of the clay, in the closing stages of Lake Shawmut, that the Charles first began to follow its present course below the Harvard bridge. That the erosion of the clay, producing all the depressions now occupied by the inner harbor, was subaerial and not marine, — fluvial and not tidal, — and that it extended over a long time, are indicated by the superficial yellowing of the clay through the oxidizing influence of the atmosphere; the oxidation extending commonly to depths of 0 to 10 feet below the

present upper surface of the clay, even under the bed of the river. This is an important point, since it proves conclusively that the estuary of the Charles is not due to tidal scour, but is the product of the river at a time when the land stood higher relatively to the sea than now.

During the subsequent slow subsidence of the land the erosion of the bed of the river ceased, and, instead of being further degraded, it was somewhat aggraded by the deposition of sand and fine gravel to varying depths; the borings for the Charles River bridges showing, resting unconformably upon the eroded surface of the blue clay, from 0 to 20 feet of sand and gravel, the prevailing thickness being from 5 to 10 feet. This deposit, which appears to become thicker landward and thinner and less continuous seaward, is probably in part marine, — a beach formation, just as we may now find at various points about the harbor beaches of sand and gravel forming over the blue clay as well as the bowlder clay. In part, also, it may be regarded as residuary, an accumulation of the stones once incorporated with the blue clay which has been removed by fluvial erosion.

The harbor as we now know it came into existence with the subsidence of the land to approximately its present level, and the inner harbor, at least, is confined almost wholly to the valleys which had previously been formed by fluvial erosion in the blue clay. With farther subsidence, carrying these deposits below the sea level, the sand and gravel gradually gave way to the silt, or the black, carbonaceous, sandy mud or muddy sand, which everywhere forms the immediate floor of the harbor below the Boston base.

Since the blue clay is the principal deposit above the bowlder clay, it demands special consideration. Careful mechanical analyses of the blue glacial clay of this region show that it invariably contains a large proportion of quartz flour, which detracts but slightly from its clayey qualities, while adding to its value for brick making, etc., by tempering the clay. At its higher levels, and almost everywhere above the low-tide level, the clay has been, as previously noted, superficially oxidized to a buff or yellow color. *The fact that the yellow or oxidized clay, and also the oxidized bowlder clay, is found from 10 to 20 and even 30 feet or more below low tide, indicates that the glacial lake was drained and the deposit exposed to the air for a long time before the land subsided to its present level relatively to the sea.*

Both the oxidized and unoxidized clay are naturally of a very stiff, tough and impervious character; and this, together with the considerable weight which they bear, must keep them comparatively dry, or free from any excess of water. The oxidation makes the clay, and also the bowlder clay, harder and firmer, by cementing the clay particles by iron oxide; and this may explain the fact that the boring records often indicate "hard clay" above, passing downward through "stiff clay" to "soft clay." As regards its imperviousness, it must be noted that the formation as a whole in its natural position must be more impervious to the overlying water of the harbor than filtration experiments with a representative series of samples would indicate; because the stratification of the clay must be strictly horizontal, and the highly impervious or non-pervious layers of plastic clay prevent the water from gaining access to the occasional relatively pervious sandy layers.

One of the most interesting sections, as regards the light which it throws upon the relations of the blue clay, is that based upon the borings made preparatory to dredging on the south-west side of the Bird Island flats. This shows, toward the west end of the flats, and from the bottom upwards: first, bowlder clay, forming a well-defined valley,

which is filled with, second, blue clay, the blue clay being soft below and passing upward through stiff to hard, the hard clay being rather thin, and in part yellow instead of blue, as the result of oxidation.

The Silt.

"Silt" is used here as a general name for the recent deposits (including those now forming), which are of a fine or muddy character. The blue clay is covered normally by 2 to 5 feet or more of soft, black (carbonaceous), sandy mud, or, more properly, a fine, muddy sand, which commonly contains shells or fragments of shells, and is thus strongly contrasted with the blue clay. Wherever streams had excavated hollows in the surface of the blue clay, these are partially or wholly filled with silt, which there attains an exceptional thickness, — 15 to 20 feet in some cases. Other instances where this sandy silt has an exceptional thickness are best explained as due to the dredging of the silt and its use for filling. In some instances, also, the silt is less carbonaceous, and passes into a fine sand.

The silt is an entirely loose and uncompacted deposit, which is easily moved or drifted about, like sand on a beach, by the action of the current; and hence areas from which it must once have been removed by dredging, as about the wharves, are now in general covered by it again, so that it is, in fact, a nearly universal deposit in this part of the harbor. That the silt is very sensitive to variations in the force of the currents is shown by the fact that in a more sheltered area, like the angle between the Charles and Mystic rivers, off the Navy Yard, it attains a much greater thickness, — commonly 10 to 15 feet, and a maximum of 25 feet. The fact that the deposition of this relatively coarse material between Boston and East Boston is almost at a standstill now is proof sufficient that the deposition of the blue clay belongs entirely to the past, and to a somewhat remote past; *for we have incontestable evidence that the deposition of this sandy silt began a long time ago and has witnessed a notable change in the relative levels of the land and sea.* Innumerable borings and excavations in the low lands all about Boston and in the valleys of the Charles and Neponset rivers, etc., have shown this highly fossiliferous silt, containing many shells no longer living in Boston harbor, resting upon the blue clay and covered by a considerable thickness of peat, the peat being largely now below sea level, and thus proving a subsidence of the land. This postglacial subsidence, tending to deepen the harbor, has made the conditions increasingly favorable to the deposition of the silt.

The slow subsidence of the land which made the accumulation of the silt possible has continued during the whole period of its accumulation; and we have good reason to believe that this subsidence is still in progress, and that the silt is still accumulating. The average or normal rate of increase of a deposit of this character must, in the nature of the case, be extremely slow; and that it has been slow in this instance, and that it began a long time ago, is proved by the fact that it has not only witnessed a notable change in the relative levels of the land and sea, but also a notable climatic change, for it contains species of shells no longer living in Boston harbor or north of Cape Cod. It is probably entirely within bounds to say that the deposition of the silt has covered a period of fully five thousand years, the rate varying according to the locality, from less than 1 foot to 5 feet in a thousand years.

It is easy to see that for any given locality the rate must diminish as the subsidence progresses and the depth of the water increases. Hence,

except for the wastes from sewers and the greater wash from streets and ploughed ground than from the natural forest covered drainage area, we may fairly assume that the rate of deposition at the present time for the estuary of the Charles is less than the average for the past. A rate above the normal is possible only in a relatively sheltered area, or where, through some change in the strength or direction of a current, silt that had been deposited is swept away, to be redeposited in a more quiet place. In other words, original deposition must be slow, and slower now than formerly, unless increased by artificial causes; and redeposition only may vary widely from the normal rate.

The silt, as now distributed, is in part distinctly or highly fossiliferous, and in part free or comparatively free from shells. Not infrequently the same boring shows it to be free from shells above, and shell-bearing below. Obviously, the most if not all of the shells are too heavy to be transported by the tidal currents, and hence where the silt is suffering erosion the shells are left behind, gradually forming a residuary accumulation or layer, which must tend to protect the silt from farther erosion, and the material which has been swept away is deposited in some more tranquil spot, free from shells. *Hence the absence of shells may be regarded as an indication of transportation from the point where the material was originally deposited*; and it is a safe conclusion that the erosion would have been much more extensive than it has been, but for the shells.

We have noted that the average rate of deposition of the silt must have been greatly reduced by the construction of sea walls, wharves, etc., in the harbor, and of dams on the river, and that the proposed dam would operate very efficiently to the same end by permanently cutting off a vast amount of material which might conceivably be swept out into the harbor, and, by diminishing the volume of the tidal reservoir, and consequently the movement of the tidal prism, lessening the power of the tidal currents to transport detritus remaining below the dam and exposed to their action. This principle appears still more important when we reflect that the *chief source of detritus in the past has been, not the river, but the shores, islands and flats of the harbor*. In other words, the prevailing movement has quite certainly been inward and not outward, the estuaries and bays being slowly but surely filled up and obliterated by contributions chiefly from the sea and not from the land. This conclusion is greatly strengthened by the obvious fact that the incoming tide must be the more efficient agent of detrital transportation, since, as I am told has been confirmed by recent observation, the cold salt water of the flood must be heavier than, and consequently will have some tendency to flow beneath, the relatively warmer fresh water of the ebb tide.

A most striking illustration of the inefficiency of fluvial transportation in this region is afforded by the fact that the Mystic Ponds, occupying kettle holes or depressions in the modified drift, due to the melting of residuary and buried masses of ice, and therefore dating from the close of the ice age, have not been obliterated or even approximately diminished in area by the action of the river during a period estimated at ten thousand years. In this connection we may also pertinently note that the shells in the silt not only protect it from erosion, but, like pebbles on a beach, favor its accumulation by affording in the dead water of interstitial spaces an opportunity for sand and silt to settle. The last thought suggests another. Apparently the shells in the silt are all dead, some of them, at least, having become so since the settlement of this region by Europeans, and probably as an incident, or indirect consequence, of the increasing density of the human population; and it may be doubted if, in the absence

of its organic accompaniment, the accumulation of silt could continue at its normal rate on tide-swept areas. On the other hand, Dr. Field has pointed out that the extinction of some if not all of the molluscan types, and notably of the long oysters, was due to an excess of silt, the abnormal length of the oysters being interpreted as due to an unconscious effort on the part of the organism to keep pace with the growth of the sediment which finally overwhelmed it. This crisis might perhaps reasonably be explained as a consequence of the deforesting and cultivation of the land, making it more easily eroded. But the tendency is clearly in the opposite direction now, for shore defences, paved streets, intercepting sewers, the covering of extensive areas by buildings and the general restriction of cultivation to turf and trees must have greatly checked both marine and subaerial erosion, and, in consequence, the complementary process of deposition must be nearly at a standstill, so far as it depends upon land-derived detritus; and we have in future chiefly to guard against the inward transfer by the deep running flood tides of the immense deposit of silt in the outer harbor. Certainly one important means to this end is the reduction of the tidal reservoirs.

While the early development of civilization in this district probably tended, for the reasons stated, to accelerate the deposition of the silt and to extinguish the organisms characteristic of the older and deeper portions of the deposit, the later developments have undoubtedly operated to retard the deposition of the silt, even reducing it below its normal or pre-colonial rate; and we may anticipate that the tendency to shoaling will be diminished by the deepening and broadening of the channel by dredging now or recently in progress.

In Conclusion.

That the water ways of the inner harbor are not due in any appreciable degree to the erosive action of the tides, and that wave erosion tends only to the obliteration of the channels, are propositions which should require no further argument. Postglacial deposition aside, the subaqueous contours are the product either of the glacial agencies in the laying down of the drift formation, or of the subaerial or stream erosion of the glacial deposits, and especially of the blue clay. That the erosion was subaerial is proved by a variety of features, and especially by its occurrence, in general, only where required by the existing drainage systems of the land, and by the superficial oxidation of both the bowlder clay and the blue clay, even where covered by a considerable depth of highly carbonaceous silt. The land valleys thus developed below the present level of the sea were drowned by the subsequent subsidence which made possible the deposition of the silt in them. That the rate of subsidence has, in the main, exceeded the rate of deposition of the silt, the channels deepening in spite of the deposition, is obvious, for otherwise the channels must have been filled and obliterated; and that the subsidence is probably still in progress is indicated by many facts noted on this and other parts of our coast, such as the submerged forests and peat beds, and the wearing away by the waves of aboriginal shell heaps and graves. But that the rate of subsidence has probably diminished would seem a safe inference, in view of the extensive development over the inter-channel areas of eel-grass flats, subsequently, in large part, converted into salt marsh, on which peat has formed more or less extensively. In fact, the breadth of fully developed marsh in some parts of the harbor, and the approximately uniform elevation of even our broadest beaches, such as Nantasket, are suggestive of a good de-

gree of stability at the present time; * and that the subsidence has been more or less intermittent is indicated by peat beds interstratified with the silt, and now 10 to 20 feet below the minimum elevation (high tide) at which peat can form. That the movement has not actually been reversed, or at least that the downward movement has dominated throughout postglacial time, is indicated by the facts stated, and also by the absence of the carbonaceous silt, with or without its characteristic fossils, above sea level.

That the silt deposition has in the past lagged far behind the subsidence is obvious, the average thickness of the silt being but a small fraction of the average depth of the harbor to the bottom of the silt. We are thus brought once more to the conclusion that only redeposition of the silt, or its transfer from one point to another, like drifting snow, can lead to appreciable shoaling of the harbor.

The argument that if the tidal scour were diminished, as it would be by any reduction of the tidal reservoir, Boston harbor would fill up and become shallow, like Quincy and Dorchester bays, where there is very little tidal scour, is based on the assumption that these bays were once deep, and have silted up. But this assumption is wholly unwarranted. In the case of Quincy Bay, between the Neponset River and Weymouth Fore River, there is no tributary stream of sufficient magnitude to have excavated, during the time when the coast was more elevated, channels comparable in depth and breadth with the lower estuary of the Charles. The known facts indicate, rather, that the low sand plain of North Quincy extends eastward under this part of the harbor, affording a foundation for the broad areas of eel grass, in the meshes of which some mud has been slowly entrapped; but that the mud or silt has attained important thickness is improbable.

In Dorchester Bay it appears, from the borings made in connection with the construction of the main drainage tunnel, that in ancient times, prior to the general subsidence of the district, the Neponset River excavated a channel in the blue clay to a depth of between 50 and 60 feet below the present low-tide level, and that in this channel the silt now has a maximum thickness of about 25 feet. It should be noted, however, that, encircled as it is by land largely composed of *modified drift in the form of fine sand*, the conditions have here been exceptionally favorable to the comparatively rapid accumulation of the silt. It is easy to see that, during the slow submergence of such low, sandy tracts as we have in North Quincy and the eastern part of Dorchester, the sand would be worked over extensively and deeply by the waves, and much carbonaceous mud incorporated with it, and the sandy silt thus developed at a much more rapid rate than would be possible after submergence became an accomplished fact.

The bowlder clay which elsewhere constitutes so large a part of the shores of the harbor, particularly around the lower part of the estuaries of the Charles, the Mystic and the entire upper harbor, erodes much more slowly, and, when worked over, as during the slow subsidence, yields to the waves chiefly stones and gravel which remain on the beach, and quartz flour and clay which can not settle in the tidal channels, but are likely, so far as not entrapped in the meshes of the eel grass, to be swept out to sea by the ebb, and deposited in deep, quiet water off shore. This enables us to understand how it is that the channels of the inner harbor have survived submergence, and that in some cases they

* As previously referred to, the State geologist of New Jersey has deduced from varied and manifold data a probable rate of subsidence of the coast in the vicinity of New York harbor at the present time of about 2 feet per century; and yet the beach and marsh developments of that coast are fully equal to those of Boston harbor.

are almost bare of silt. It is especially interesting to note that on the shores of the inner harbor, in Boston, Charlestown, East Boston and South Boston, easily eroded, sandy drift is conspicuous by its absence, and the floor of this part of the harbor is but lightly covered by silt; but above the Charlestown bridges, in Cambridgeport and Brookline, the shores are largely fine sand, and the upper portion of the estuary of the Charles is deeply silted above the surface of the blue clay.

Respectfully submitted,

W. O. CROSBY.

Appendix No. 8.

Memoranda on Harbor Scour, etc.,

SUBMITTED

IN ANSWER TO SUNDRY QUESTIONS BY H. S. PRITCHETT, *Chairman*, AND J. R. FREEMAN, *Engineer*.

By Lieut.-Col. W. A. Jones, *Corps of Engineers, U. S. A.*

To the Committee on Charles River Dam.

Gentlemen: — I have been asked to carefully review the evidence relative to the probability of shoaling in Boston harbor, if the Charles River dam is built, laid before the Massachusetts Board of Harbor and Land Commissioners in the year 1894, in the light of such experience as I have had personally while studying and supervising sundry works of river and harbor improvement for the United States government, under the direction of the chief of engineers.

I have visited the region in question in company with your engineer, and have examined the results of certain measurements of velocity of the currents, made by him. At his request I have also furnished sundry references to reports of the chief of engineers and other publications relative to the velocities and conditions required for producing scour on the channel beds.

I have summed up the points covered in conversation in the following memoranda, without attempting to elaborate them into a formal report.

The Evidence and Conclusions in Report of 1894.

The evidence and conclusions concerning the deterioration of the harbor channels in this report of hearings before the Massachusetts Harbor and Land Commissioners in 1894 appear to be based mainly upon the conclusions set forth in the various reports of the Board of United States Commissioners on Boston Harbor, between the years 1861 and 1865. The guiding principles of those reports are summarized in general terms as follows: —

"*A.* — Tidal harbors depend upon their interior reservoirs for the preservation of their channels."

That was a general principle of harbor hydraulics laid down more than forty years ago, and the engineers of to-day do not accept it as of application to all tidal harbors. They have found such harbors whose channels do not depend upon their reservoirs, and the harbor of Boston is one. Baltimore harbor has no tidal prism of consequence, yet dredged channels maintain themselves there very well.

The pertinent facts of precise observation show that the tidal currents in Boston harbor are not at this time either moving the normal material at the bottom of the channels or depositing sediment to any serious

extent upon them. Moreover, this material is limited in quantity, and so very finely divided that, even with a considerable reduction in bottom velocities, the quantity deposited in the channels will be movable by dredging at a small cost.

The facts determined by the United States Board's measurements in Boston harbor are entirely insufficient to justify the application of its principle "*A*" to that harbor.

The effective eroding energy of a moving body of water is a function of: —

1. Its velocity where in contact with the material which confines its flow.
2. Its volume.
3. The character of the material; its susceptibility to disintegration in the presence of water; the size and weight of its particles.

The velocities of tidal currents measured by this Harbor Board of 1860–65 were velocities near the surface, and their measurements of deep velocities were by imperfect methods, long since abandoned in favor of the modern current meter. They did not get near enough to the bottom to measure the velocity of the water in contact with the bottom, on which the scour depends.

The effective eroding velocities were unknown to the Board. Moreover, at that date the science of geology was in its infancy, and the development of the thirty-seven years since its final report was made have shown the existence of drowned valleys and other possible causes than tidal scour for the creation of channels.

The fact that the dredged portions of the channels of this harbor have not silted up to any material extent during a period which covers a very large diminution of the tidal prism, shows that the silt which gets into the channel waters is too finely divided and too low in density to permit its being deposited while in those channels to an extent sufficient to cause trouble. It has had to seek rest in the stiller waters of the eddies which border them, or in those of the neighboring flats and shoals.

To sum up, we may say that the *United States Board had not before it sufficient facts of precise measurement to justify it in placing Boston harbor in the class of tidal reservoir harbors. On the other hand, such facts have now been obtained sufficient to show that this harbor does not belong to that class.* Besides, in engineering, as well as in science in all its varied applications, the "authorities" of to-day are not all those of yesterday; and a great deal that was accepted fifty years ago is not accepted to-day, in the light of our greater knowledge and more precise means of measurement. And, furthermore, there have been placed in the hands of the modern engineer two exceedingly powerful resources for the creation and maintenance of channels: (1) the high-powered dredge; (2) high explosives. With these he can carve the earth beneath the waters at an exceedingly low cost; and the equilibrium between commercial values and the cost of making and maintaining the channels of navigation has been changed in an extensive and striking manner, giving far greater weight in the balance to the former. The engineer can now pretty safely say to commerce: State your wants, and I will secure them at a reasonable cost.

As a matter of fact, *the whole question of Charles River basin as a tidal reservoir was settled by Congress when it appropriated the money for creating a channel* 1,200 *feet wide and* 35 *feet deep from the wharves of Boston to President Roads, and thence* 1,500 *feet wide and* 35 *feet deep to the ocean; the same to be wholly done by dredging and blasting.* If

Congress, under the advisement of the United States Engineers, had been of the opinion that Boston harbor was a reservoir harbor, — that is, one whose channels were maintained and dependent upon its tidal reservoirs, — it could not have been justified in overloading those reservoirs with the great 35 foot channel, 1,200 to 1,500 feet wide, from Boston to the ocean. If those channels were dependent upon these reservoirs, how, after the largest of them had had its tidal prism reduced from 823,000,000 cubic feet to 323,000,000 cubic feet since 1857, could there be any reasonable expectation that they would maintain, or save from rapid deterioration, a channel so very much greater than the one which should now be wavering in the balance of usefulness?

The engineers of the United States service are not bound by old authorities and precedents, except in so far as they are confirmed by precise observations and measurements of the *essential* facts in each particular case. There can be but few *general* laws in harbor engineering, for the reason that the *quantity of water* factor, and its performances under proposed conditions, are largely functions of weather and climate, and this field of science has so far eluded our equations. Instead of fitting our practice to follow general laws, applicable to harbors in general, we must base it on a careful observation of the facts about the particular case in hand.

Commerce and Navigation.

So far as the commerce and navigation of the river through and above the proposed dam is concerned, *holding the ponded water at a constant level, giving a fixed depth of 2½ feet less than those at extremely high tides for a few hours only each month, will afford a more efficient aid to commerce than a highway whose level oscillates twice a day, vertically, over a range of 9 or 10 feet.* A vessel of greater draught than could navigate the proposed basin will have, under the present river conditions, so much detention, on account of the fluctuations, and during the time when the tide levels are below grade 8, as to create expenses much in excess of the gains to be made on account of the greater draught. But over all that lies the really vital fact, that *it will be perfectly feasible to put such a depth of water upon the mitersill of the lock, and give such increased depth in the basin by dredging, as to make the new state of affairs very much more favorable for commerce and navigation than the old.* The question of damage from the additional time lost by ice, as a result of fresh water freezing more readily than salt, is now mainly academic. Better wait and see what it amounts to, with the sure knowledge that, if the increase over the present detention should rise to the dignity of a serious factor in the problem, it will be a factor which can surely be handled by well-known means.

The Old *v.* the New.

The theories developed by the Board of United States Commissioners, after ten years of observation and study in Boston harbor, cluster around one central theme, which is, in substance, Put your whole trust in the forces of nature heretofore in operation at the site.

Fifty years later, the modern engineer develops these forces or curtails them, and introduces his great forces of dredging and blasting.

The two-jetty harbor involves a very serious manipulation of the forces which go to make tidal reservoirs behind them. Their effects in creating a head behind them and increased velocities between them have been carefully studied and are broadly known, but their effects in reducing the tidal prism upon the interior channels are not so well under-

stood by the general public. In such cases as South Pass, Charleston, Galveston, St. Johns River, Brunswick, Ga., etc., an artificial excavating effect has been created over short, narrow channels on ocean bars through the increased velocities created by the jetties. In these *there has been a reduction of the tidal prism, which has a reducing effect, at all interior channels within the tidal range, upon the velocities of both flood and ebb tides.* The interior channels in those cases correspond to the inner channels of Boston harbor, where, as can be easily demonstrated, will occur all of the reduction in scouring effect that may be caused by the elimination of the tidal prism of Charles River.

And so, in many cases on the coasts of the United States, the government engineers, after elaborate consideration, have deliberately sacrificed volumes of tidal prism, well knowing that, whatever may be the consequences, they can cheaply be remedied by dredging.

As an illustration of this, I have sent you the records of the mean annual range of tides in Charleston harbor, S. C., from which it will be seen that, whereas from 1883 to 1885, inclusive, the mean range of the tide was 5.23 feet, this was reduced after the construction of the jetties to 4.90 feet, a difference of .35 feet, or 7 per cent.; and during the year 1897 a still larger decrease was noted.

Unsanitary Effect of Ground Water.

I have been much interested in reading the evidence given in the report of 1894 upon this subject, also that given in the recent hearings before your Board, because of having, from the nature of my work, been called to spend much time in places where the ground water was near the surface; and the result of my observation is contrary to some of the opinions expressed as to its dangers. Without taking space to go into this matter elaborately, I will refer to two notable instances among many that could be cited, and which, if time permits, you may be interested to investigate, — both well-known health resorts, and particularly sought on account of their well-known freedom from malaria.

Atlantic City, N. J. — Here at the Light House grounds, typical of larger areas, we find in summer the plane of saturation about 3 feet below the surface and in winter only 1 foot below the surface.

Old Point Comfort, Va. — Long celebrated for its healthful and nonmalarial conditions. Here in 1894 the United States Engineers made an elaborate series of observations upon the level of the ground water at representative locations, and at the principal points of observation it was found from 1.5 to 4 feet below the surface, and fluctuating to a slight extent from the rise and fall of the tide.

Appendix No. 9.

A Letter from Hiram F. Mills, Hydraulic Engineer,

CONCERNING

DUBUAT'S EXPERIMENTS UPON THE EROSIVE ACTION OF CURRENTS OF WATER.

Office of the Proprietors of the Locks and Canals on
Merrimack River, 66 Broadway,
Lowell, Mass., Nov. 1, 1902.

Henry S. Pritchett, LL.D., *Chairman Committee on Charles River Dam.*

Dear Sir: — In response to your letter of October 30, I give some data to which I had previously called your attention, which indicate a serious error which has entered into many of the conclusions regarding the maintenance of Boston harbor which have been reached in the past forty years. The error is contained in the tenth and final report of the commission to investigate and report upon the condition of Boston harbor, with a view to its preservation and safety for the interests of navigation, which commission was made up of General Delafield, U. S. A., Professor Bache, superintendent of the Coast Survey, and Com. C. H. Davis, U. S. N. The report was published as Boston City Doc. No. 50, 1866, and its error is contained in the report of the Harbor and Land Commissioners for 1894, Public Doc. No. 11, 1895, p. 18, which I quote:—

"Among the observations recited in the tenth report aforementioned were some relating to the velocity of the river and tidal currents, the results of which are tabulated. From these it appears that the velocities of ebb and flood currents rarely exceed 1 mile an hour between Boston and East Boston.

"According to Dubuat, a velocity of .15 of a mile an hour is sufficient 'to remove clay fit for pottery,' with which the stiff clays forming the natural bed of portions of the harbor are classed. It further appears, from the periods during which the velocities below the bridges exceed .3 of a mile per hour, that the ebb maintains this excess for five hours eighteen minutes, the flood but three hours fifteen minutes. Dubuat's experiments show that sand may be moved or rolled by a current of .3 of a mile per hour, so that at one station, by this combination of river and tidal forces, a grain of sand would daily make two journeys, one up river, represented by 3.15, the other seaward, by 5.18. The seaward gain is therefore fully in the proportion of 5 to 3; there is, then, at this point power sufficient to keep the channel free. Except for the tides

Amount of Shoaling in Boston Harbor

Group	Date of Last Dredging	By Surveys: Depth of Shoaling shown in this Square from Differences in Survey, 1835 to 1861 (Feet)	1861 to 1888 (Feet)	1861 to 1892 (Feet)	Reference Square See Map	By Sample Cores: Number of Boring	Depth below Surface of Bottom of Harbor in Feet, From To	Material of Core between Given Depths
Group No. 6	1879	-3.4	—	—	q 38	1	0.0 - 0.7 0.7 - 1.6	Sand and Shells Blue Clay
Group No. 6	1902	-2.0	—	—	p 37	2	0.0 - —	Blue Clay
Group No. 6	1902 1879 1879 1879	2.0	—	—	q 37	3 4 5 6	0.0 - 1.6 0.0 - 1.0 0.0 - 1.3 0.0 - 0.9	Blue Clay Blue and Yellow Clay Blue Clay with Gravel Blue Clay and Small Stones
Group No. 6	None	-2.0	-0.7	1.0	v 32	7	0.0 - 0.5 0.5 - 1.1 1.1 - —	Black Sand and Clay Black Sand less Clay Blue Clay
Group No. 6	None	0.1	0.3	1.0	v 31	8	0.0 - 0.9 0.9 - 1.4	Black Sand and Clay Blue Clay
Group No. 6	None	1.2	-0.4	—	u 30	9	[illegible] - 0.1 [illegible] - 0.5 [illegible]5 - 1.5	Sand and Gravel Clay Sand and Gravel Yellow Clay
Group No. 6	None	0.7	0.0	0.0	v 30	10	0.0 - 0.5 0.5 - 0.9	Black Sand and Gravel Hard Yellow Clay
Group No. 1	None	—	1.6	3.0	w 30	11	[illegible] 0.4 [illegible] 9	Sand Gravel and Clay Blue Clay and Small Stones
Group No. 1	None	-2.0	1.0	—	x 30	12 13	[illegible] 0.3 [illegible] 1.7 [illegible] 0.5 [illegible]5 - —	Black Mud and Clay Blue Clay Black Sand and Gravel Blue Clay and Sand
Group No. 1	None	0.8	-0.1	1.0	w 29	14	0.0 - 2.8	Sand and Blue Clay
Group No. 1	None	-0.8	0.7	2.0	x 29	15	0.0 - 0.2 0.2 - 0.8 0.8 - 1.0	Black Mud and Sand Blue Clay Sand Gravel and Clay
						16	0.0 - 0.1 0.1 - 1.2	Black Sand and Clay Clay and Sand
						17	0.0 - 0.1 0.1 - 1.2 1.2 - 2.2	Mud Black Sand and Shells Blue Clay
Group No. 1	None	-1.0	0.5	—	y 29	18 19	0.0 - 0.3 0.3 - 1.2 0.0 - 0.2 0.2 - 1.3	Mud Yellow Clay Sand and Clay Blue Clay
Group No. 2	None	1.2	-0.9	0.5	F 26	20	0.0 - 1.2	Mud with Odor
Group No. 2	None	-0.8	0.3	1.9	G 27	21	0.0 - 0.3 0.3 - 2.8	Black Mud Blue Clay and Sand
Group No. 2	None	3.0	-1.6	3.0	G 26	22	0.0 - 2.5	Fine Blue Clay
Group No. 2	1895	—	—	—	H 27	23	0.0 - 0.8 0.8 - 1.4	Soft Clay and Sand Clay Sand and Sticks

For Continuation of Table See Upper Right Hand Corner of Sheet

Amount of Shoaling in Boston Harbor

Group	Date of Last Dredging	By Surveys: Depth of Shoaling shown in this Square from Differences in Surveys, 1835 to 1861	1861 to 1888	1861 to 1892	Reference Square See Map	By Sample Cores: Number of Boring	Depth below Surface of Bottom of Harbor in Feet, From To	Material of Core between the Given Depths
Group No. 3	None	2.0	0.6	2.3	F	24	0.0 - 0.9 0.9 - 1.8 1.8 - 2.0	Black Sand Sand and Clay Blue Clay and Gravel
						25	0.0 - 1.4 1.4 - 2.3 2.3 - 3.3	Mud and Shells Sand and Shells Blue Clay and Sand
						26	0.0 - 0.8 0.8 - 1.6 1.6 - 2.6	Black Sand and Shells Sand and Clay Sand and Clay
						27	0.0 - 1.0 1.0 - 5.0	Black Sand Sand and Shells
Group No. 3	1878	—	—	—	D 19	28	0.0 - 1.5 1.5 - 3.0 3.0 - 5.0	Black Sand Black Sand Blue Clay and Sand
Group No. 3	1883 to 1886	—	—	—	F 22	29	0.0 - 1.5 1.5 - 3.8	Black Sand Blue Clay
Group No. 4	1896	—	—	—	L 25	30	0.0 - 0.5 0.5 - 1.5	Black Sand and Clay Yellow Clay
Group No. 4	None	—	—	—	M 25	31	0.0 - 1.6 1.6 - 4.0	Mud Yellow Clay
Group No. 5	[illegible]		—	—	K 21	32	0.0 -	Probably Rock
						33	0.0 - 0.5	Blue Clay Sand and Shells
Group No. 5	1880	—	—	—	J 20	34	0.0 - 0.2 0.2 - 2.0	Mud Yellow Clay

COMMITTEE ON CHARLES RIVER DAM
Mass. Acts of 1901, Chapter [illegible]

COMPARISON OF DEPTHS IN BOSTON HARBOR

According to Surveys of
1835 by PERHAM for the Massachusetts Legislature.
1861 by A. BOSCHKE for the U.S. Commission on Boston Harbor.
1888 by S. HAAGENSON for the U.S. Harbor Line Board.
1892 by the U.S. Coast and Geodetic Survey

Also

LOCATION AND RESULTS OF SUNDRY BORINGS

MADE AT SITE OF SUPPOSED SILT DEPOSITS BY W.E. SPEAR C.E. DECEMBER 1902

SCALE 1:10000

LEGEND

The Average Differences in Depth in feet for each Square between successive Surveys are shown in the Corners of the Squares thus:

Between 1835 and 1861

Between 1861 and 1888

Between 1861 and 1892

Borings shown thus

APPARENT DEPOSITS IN BLACK (SURVEY)

APPARENT DEEPENING IN RED

NOTE

The Data for these Changes in Depth is found on
1. Map of Changes in Boston Harbor by the U.S. Harbor Line Board of 1888, Sheet C.
2. Map of Changes in Boston Harbor by the U.S. Harbor Line Board of 1888. Sheet D.
3. Map of Changes in Boston Harbor by the Mass. Harbor and Land Commission, April 1895.

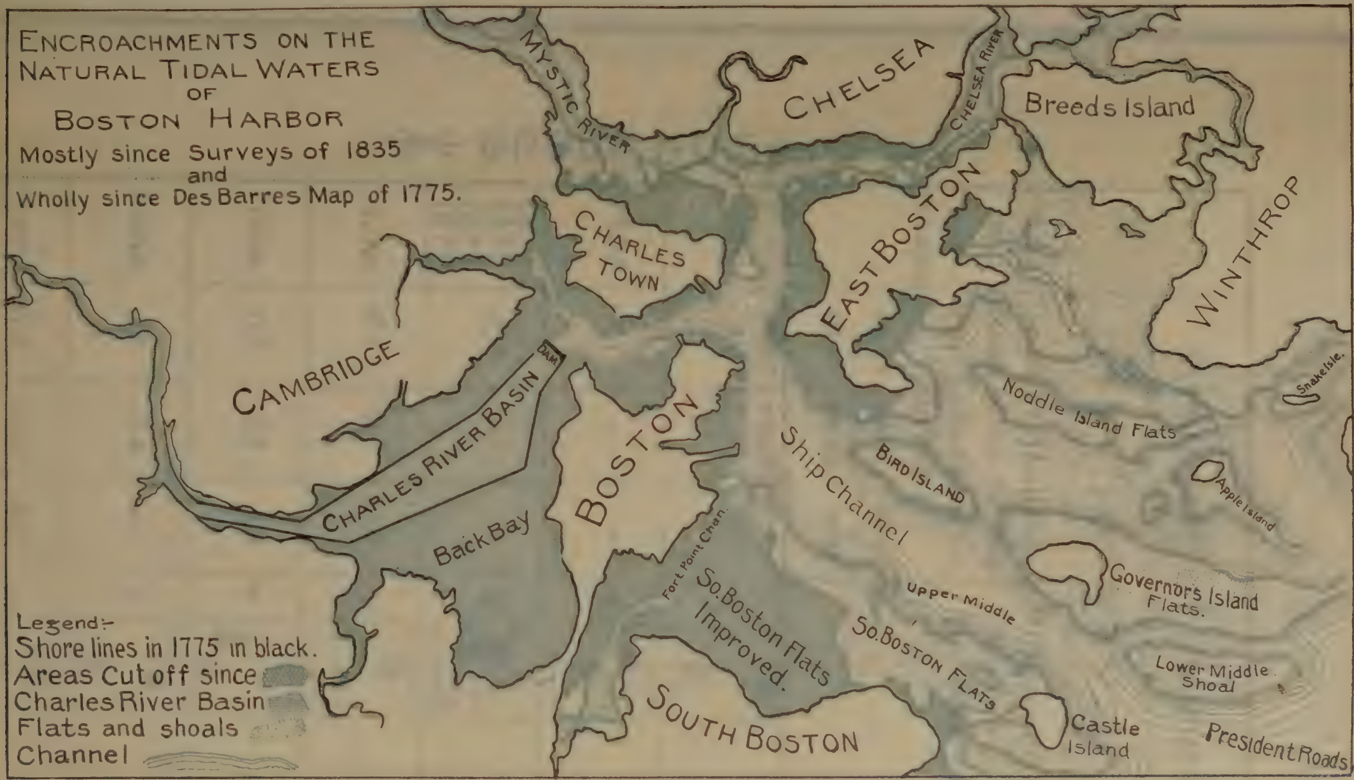
On each of the above three Maps the Differences are given in Cubic Yards for each Square but these divided by the Area correspond to the even Feet given on this Diagram. It is to be noted that these various Soundings were made (probably with ordinary Sounding Lead and Hemp Line, tagged off in Feet) in Water of a Depth from 20 to 30 feet or more, with Surface oscillating and with a Current commonly about 2 Feet per Second at Mid Tide which would tend to sag the Line and increase the apparent Depth at Mid Tide as compared with Slack Water. An extreme Precision of Measurement was probably not expected. See comparison of Surveys of 1893 in sub plan

John R. Freeman
Chief Engineer.

5000 4000 3000 2000 1000 FEET

MILES

GEO. H. WALKER & CO. BOSTON



ENCROACHMENTS ON THE
NATURAL TIDAL WATERS
OF
BOSTON HARBOR
Mostly since Surveys of 1835
and
Wholly since Des Barres Map of 1775.
MYSTIC RIVER
CHELSEA
CHELSEA RIVER
Breeds Island
CHARLES TOWN
EAST BOSTON
WINTHROP
CAMBRIDGE
CHARLES RIVER BASIN
DAM
BOSTON
Back Bay
Snake Isle.
Noddle Island Flats
Ship Channel
BIRD ISLAND
Apple Island
Fort Point Chan.
So. Boston Flats Improved.
Upper Middle
So. BOSTON FLATS
Governor's Island Flats.
Lower Middle Shoal
SOUTH BOSTON
Castle Island
President Roads
Legend:-
Shore lines in 1775 in black.
Areas Cut off since
Charles River Basin
Flats and shoals
Channel

Appendix No. 10.

Soundings and Borings in Harbor,

CONCERNING THE SUPPOSED SHOALING OF BOSTON HARBOR, SHOWN BY COMPARISON OF SOUNDINGS FROM 1835 TO 1892. ALSO MEASUREMENTS OF THE DEPTH OF SILT ON BED OF HARBOR.

By John R. Freeman, *Chief Engineer.*

Conclusions have sometimes been drawn, and strongly maintained, to the effect that Boston harbor has suffered noteworthy change in depth within the past fifty-eight years by reason of a deposit of silt permitted by the enfeebling of the harbor currents that necessarily followed the cutting off of the tidal volume caused by the filling of the Back Bay lands, the filling of the Cambridge shore, and sundry other cases of encroachment on the water space and pushing out of the shore line.

That the extent of these encroachments on the tidal waters immediately about Boston has been very large, will be seen by studying the map opposite this page, which shows the shore lines and edges of the tidal flats as given on the old Des Barres map of 1775. On this map the present shore lines have also been laid down, and it is of interest to note how small the area remaining in the Charles estuary which it is now proposed to cut off is, in comparison with the area of water surface that has been cut off within the past fifty or one hundred years. *The tidal area now proposed to be cut off is only 66 per cent. as great as that cut off from the Charles estuary above the Charles River bridge in past years without having produced noteworthy shoaling.**

On page xviii of the Harbor Commissioners' report of 1894, upon the proposed Charles River dam, there is presented a table which states the amount of shoaling between the successive surveys of the harbor since 1835. In the appendix to the volume of evidence and arguments of 1894, before the Harbor Commissioners, several maps of the harbor are presented, which exhibit the net change found between the several surveys, in cubic yards for each square of 200 or 400 feet. When the total change shown by these maps is added up, the figures at first view indicate a good deal of shoaling. The form of statement given on these maps which states the cubic yards of shoaling or deepening for each 200-foot square is less easily comprehended in a brief study than a simple statement of the change in depth, such as is presented in the next folding map, entitled "Comparison of Depths in Boston Harbor."

New Comparison of Surveys, Ancient and Modern. — I have had these maps redrawn and combined in a single map, inserted opposite p. 378, on which the information presented by all of these previous maps on shoaling and deepening is stated in terms of depth. Red

* Evidence, Las Casas, p. 28: Original tidal area above Charles River bridge, 2,250 acres; amount filled in or cut off, 1,356 acres; present area, 894 acres.

figures show deepening or scour, black figures show deposits or shoaling. The average net change in depth in each square, found by comparing the successive surveys, is given by a single figure in one corner of the square, and the three different figures in the several corners of each square are each for a different comparison between surveys.

It will be noted that the black figures, which indicate shoaling, predominate.

The particular corner of the square in which a figure stands indicates to which sets of surveys it refers. This is fully explained by the sketch and note printed on the plan just beneath its title.

It will be noted that the sum total of deposit (assuming that the surveys of 1835 and 1892 are equally correct) is not a formidable quantity for the principal portions of the harbor, or those parts most frequented by ships. The change is mainly off the Charlestown shore.

Down in the main harbor, at and below the ferries, the red figures showing deepening are seen to be mixed in with black figures showing shoaling in a way that may suggest either remarkably capricious and shifting forces at work, that first caused deepening and then caused shoaling, or these differences may suggest a lack of precision in these surveys.

The survey of 1892 followed so soon after that of 1888 that probably very little change in depth occurred between them, yet the soundings show very considerable differences; and this again suggests lack of precision of measurement. Some of these apparent changes in depth, particularly in the region near the ferries and for half a mile below, are hard to explain, if we accept the measurements as exact.

The total apparent shoaling from 1861 to 1888 or 1892 was greater at the mouth of the Mystic and off Chelsea Creek than it was off the mouth of the Charles; yet during this time the Charles had surely received more of sewage sludge, and its margins had been subject to greater encroachment. Moreover, in the period from 1835 to 1861, if these surveys are to be trusted, there had been a large amount of deepening or scour over the same territory, for which no adequate reason appears in the history of matters affecting the strength of current, because of which material deposited in the early days prior to 1835 should have been scoured out in the twenty-six years from 1835 to 1861.

The internal evidence, therefore, points to caution in the use of these old surveys for the purpose of measuring the depth of deposit or scour; and when we consider that these depths were probably measured rapidly with a comparatively light weight and a hemp line tagged off in feet, which line would be sagged out by the current at mid-tide and stand plumb at slack water, and consider also that the measurement is read off quickly from an oscillating surface, that the limit of precision was to the nearest foot, and that tide gauge errors sometimes creep in, the discrepancies found in the harbor between Boston and East Boston are not impossible of explanation. Off Charlestown the differences appear to be too large to be thus accounted for.

To illustrate the lack of extreme precision that may sometimes occur in soundings taken in deep moving water, by the methods commonly followed in measuring depths for the use of navigators, I have entered on this plan a small sketch* showing the discrepancies in the recent work in a part of the same territory, by a sounding party† from what

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* Correction: on this small sketch the contours should read in even fathoms instead of even fives, as shown; therefore, substitute 12 for 15, 18 for 20, 24 for 25. The interval between surveys was about fifteen months, instead of two months, as stated.

† Although technically the same party, it is possible that different men read the depths, etc.

we believe to be the foremost hydrographic office in the world. It will be noted that the depth averaged 2 feet deeper at the second observations, and that these differences — which are surely errors of measurement* — are as great as the average differences in depth between the ancient and modern surveys of that part of the harbor lying between Old Boston and East Boston, from which the progressive shoaling of the harbor due to the encroachments of the tidal prism has been argued; and some of these differences are nearly as large as the average differences between the ancient and modern maps of the harbor bottom off Charlestown.

It appeared to me that there were more conclusive data easily within reach from which the possible extent of the recent shoaling could be learned, for, from the studies of the geologist and from the current report of those who are familiar with the experience gained in dredging in Boston harbor and familiar with the borings for the East Boston tunnel and other borings, it may be accepted as absolutely certain that wherever the hard blue clay, free of shells, is found, this represents the original floor of the harbor, and that this blue clay was deposited thousands of years ago.

Therefore, the thickness of sand, sludge or silt found on the top of the blue clay represents the entire net accumulation of silt for some thousands of years past, except as silt once deposited may have been afterward scoured off by a shifting of currents.

Therefore, if we cut down into the blue clay and measure the thickness of the overlying silt, and find this thickness smaller than the alleged shoaling between two surveys, it is obvious that the depth as measured in one or the other of these surveys must have been inaccurate, or only approximate.

The general experience in dredging in Boston harbor is that the excavation has been mainly in deposits of clay or hardpan, and not in silt. To have had a chartered dredging outfit for the present investigation, and gone from point to point and carefully taken up a few buckets full at each station and examined the material, would have been very instructive, but slow and very expensive; therefore, the method was devised that is described below.

Borings for measuring Depth of Silt in Harbor.

Thirty-four sample cores, from 3 to 5 feet in length, were cut in various representative localities by means of driving a long piece of 2-inch wrought-iron pipe, having a sharp bottom edge, down into the bed of the harbor, and then pulling it up and pushing the specimen out of the pipe with a piston. A good many more samples would have been taken had not very severe freezing weather set in suddenly, which rendered further work of this kind impracticable with the means at hand.

This core-cutter pipe was about 8 feet in length, and was hung by appropriate tackle from a crane mounted on a dory catamaran, designed for harbor borings, that was kindly loaned us by the chief engineer of metropolitan sewers. The pipe was driven down by the impact of a 30-pound lead weight, in the form of a ring which slid freely up and down on the outside of the cutter pipe, striking against a fixed collar on the pipe, with an action something like that of a pile driver. This weight was lifted and let fall by a rope worked from the boat. In order to hold the cutter pipe vertical while starting a hole, a foot plate was attached, consisting of a boiler iron plate about 20 inches square and about ½ inch thick, having a hole and collar at its centre that let the cutter pipe move freely through it. This plate was prevented from slipping off the

* Or errors due in part, perhaps, to roughness of bottom as left by dredging, and to not sounding at precisely the same spots in the successive surveys. While this may account for individual differences, the averages should be about the same.

end of the pipe by a chain attached to the fixed collar, whose length was so adjusted as to leave the end of the cutter pipe just flush with the foot plate as it was lowered on the bottom. A loosely fitting, cup-shaped leather cap was inserted at the bottom of the pipe before lowering; this rested on top of the core of mud, and prevented the loss of fine material due to churning up the contents while driving. After the apparatus was hauled to the surface and the piston inserted to force the core out of the pipe for inspection, the leather cap proved effective in preventing loss of material. A check valve was fitted to the top of the pipe.

The plug of hard blue clay forced into the bottom end and forming commonly the bottom of the core held the material above it firmly in place while the whole apparatus was being hoisted.

The apparatus proved very satisfactory, and could be used in any depth of water. Our scow or catamaran was brought into the desired position by the gasolene launch, and then anchored by a bow anchor and a quarter anchor, so set that the force of the current held the boat steady. The position of each boring was located by sextant angles to prominent land marks.

The position of each boring and notes regarding the material found are given on the map inserted at p. 378, already mentioned.

The results may be briefly summarized as follows: —

Group No. 1.

Thirteen core samples, Nos. 7 to 19 inclusive. From an area never yet dredged, located from 300 to 800 feet off the East Boston shore, between the slips of the North and South ferries. This area has an average depth of about 43 feet at mean high tide and 33 feet at mean low tide.

Soundings near Group 1. — A comparison of the averages of the soundings made at different times in this immediate vicinity shows that between 1835 and 1861 there was very little change in depth. The depths measured on the twenty 200-feet squares in this immediate vicinity showed an average shoaling of only 0.3 foot.

A comparison of the soundings of 1861 with those of 1888 over the same twenty 200-feet squares shows an amount of deepening in some squares which almost exactly offsets the amount of shoaling in the other squares, the net result being about 0, or no change in depth in twenty-seven years over this area.

A comparison of the soundings of 1861 with those of 1892 indicates that the average depth for this same area of twenty 200-feet squares was 0.8 less in 1892 than in 1861, and this would indicate an average shoaling of 0.8 in four years' time; for it is to be noted that the comparison of 1861 with 1888, summarized in the preceding paragraph, had shown that in the twenty-seven years up to 1888 the deepening had just offset the shoaling. It is incredible, in view of the fact that no change in conditions affecting deposit or scour is known to have occurred about 1888, that, if no shoaling had occurred from 1861 to 1888 in the twenty-seven years, this apparent shoaling of 0.8 foot could have occurred in the four years between 1888 and 1892.

Sample Cores, Group 1. — The thirteen sample cores taken from this area showed an average depth of 0.4 foot of mud. Below this there is in some places 1 foot of sand and shells, and in other places none of this sand and shells, while in some few places there is nearly a foot of yellow clay; but in general the hard blue clay was found to average only about 1 foot below the top of the mud. It is therefore plain that no considerable shoaling has yet occurred in this important part of the harbor.

Group No. 2.

Three cores, samples Nos. 20 to 22 inclusive. On an area never yet dredged, located about 200 to 800 feet off the East Boston shore, between the sections opposite the South ferry slip and the Cunard wharf.

Present average depth about 40 feet at mean high tide and 30 feet at mean low tide.

Soundings near Group 2. — A comparison of the soundings over this area made in 1835 with those made in 1861 shows that in the five 400-feet squares surrounding these borings there had apparently been an average shoaling of 1 foot in the period of twenty-six years.

Comparing the soundings of 1861 with those of 1888, no shoaling is shown in the same five 400-feet squares, but an average of the measurements indicates a deepening averaging less than a foot; and thus it appears that the survey of 1888 agrees fairly well with that of 1835 for this immediate locality.

Comparing the soundings of 1861 with those of 1892, a shoaling is indicated in every square, the greatest apparent shoaling (3 feet) being in the same square in which the greatest deepening was shown by the survey of four years previous. The mean depth of apparent shoaling in these five 400-feet squares, shown by a comparison of the surveys of 1861 and those of 1892, is 1.6 feet.

Since a comparison of the surveys of 1861 with those of 1888 already noted had shown an average deepening of 0.8 foot, it is plain that a comparison of the survey of 1888 with that of 1892 must show an average shoaling of 2.4 feet in four years on this area, which is incredible.

Sample Cores of Group 2. — One boring (in 26-F) showed 1.2 feet of mud, but our four borings within this same area of five contiguous 400-feet squares, over which no dredging has ever been done, so far as the record shows, show a mean depth of mud on top of the hard blue clay averaging only 0.5 foot. This indicates that no such deposit has occurred here as the differences in the soundings described in the last paragraph would indicate, and these soundings must have been erroneous.

Group No. 3.

Four core samples, Nos. 24 to 27 inclusive. An area never yet dredged, in mid-channel opposite Long wharf, and about 1,000 feet distant therefrom.

Depth at mean high tide, about 40 feet; depth at mean low tide, about 30 feet.

Soundings, Group 3. — A comparison of the survey of 1835 with that of 1861 indicates a shoaling of 2 feet in this square during these twenty-six years. A comparison of the soundings of 1861 with those of 1888 indicates no change. A comparison of the survey of 1861 with that of 1892 indicates an average shoaling of about 2 feet.

Sample Cores, Group 3. — Two of these cores which penetrated to the hard blue clay showed an average deposit of from 1 to 2 feet on top of the hard clay, the material being black sand and clay in one case and mud and shells in the other.

The other two cores did not reach the blue clay, but penetrated sand and shells and sand mixed with clay for depths of from 2 to 5 feet. This material could hardly be classed silt, and may be of ancient origin. The absence of the blue clay leaves the test of the soundings by the sample cores more obscure in this place than ordinarily.

Sample No. 29, in group 22-F, which was not far distant from the area just described, but was within an area that was dredged between 1883 and 1886, showed 1.5 feet of black sand on top of the blue clay. This does not necessarily imply that 1½ feet of ordinary silt, as the term is commonly understood, had been deposited at this point since the time of the dredging mentioned. This deposit may be of material carried to this point in suspension from other dredging operations carried on near to this area, in a material which we are informed was of such a nature that it filled in behind the dredge. It is not unlikely that some or perhaps all of the deposit in square F-23 may have come from this stirring up of fine sand by the dredge located near by.

Group No. 4.

Two core samples, Nos. 30 and 31. No. 31 was located 400 feet from and in a line with the Boston, Revere Beach & Lynn Railroad dock, and was from an area on which no dredging has ever been done.

Soundings near Group 4. — The comparisons of surveys are not given for the square containing this boring, and are not sufficiently complete in the adjacent squares to give any reliable indication either of shoaling or of deepening.

Sample Cores near Group 4. — This boring No. 31 showed that there was a depth of 1.6 feet of mud on top of the hard, yellow, oxidized clay.

Boring No. 30, 200 feet out from the Leyland line dock, was on an area dredged in 1896, but showed a depth of 0.5 foot of black sand and clay on top of the hard yellow clay.

Group No. 5.

Three samples, Nos. 32 to 34 inclusive. Group No. 5 was from an area dredged to a depth of 20 feet below mean low water, twenty-two years ago (1880), and the boring was made at that point with a view to learning if silt had collected in this dredged channel during the past twenty years. We subsequently learned that a small amount of additional dredging was done in this vicinity between 1899 and 1902. The cores showed no noteworthy covering of sand or silt on top of the hard clay.

Boring No. 32 failed to secure any sample. When the pipe was withdrawn, the end was found battered, as though it had been pounded down on to a boulder or piece of ledge. Boring No. 33 showed the blue clay entirely exposed. Boring No. 34 showed the hard yellow clay covered with only 0.2 foot of mud.

Group No. 6.

On Man-of-War shoal, six samples, Nos. 1 to 6 inclusive. These borings were also made on some of the oldest dredged areas, with a view to learning if silt had gathered thereon during the past twenty-three years. Borings Nos. 1, 4, 5 and 6 were made on an area dredged in 1879. They indicate an average depth of mud on top of blue clay amounting to 0.2 foot.

The remaining sample cores in this group, Nos. 2 and 3, after the sextant angles had been worked up and the positions plotted accurately, were found to come on an area that had been dredged the past season. These showed the bare surface of the hard blue clay with nothing on top.

Sample core No. 28 was taken about 100 feet distant from the New York & New England Railroad dock, and at the corner of the South Boston flats, on an area dredged in 1878. This showed a depth of sand

of 3.0 feet above the blue clay. This deposit, like that found in the borings of group No. 3, is very probably due at least in part to a deposition of the fine material stirred up in other operations of dredging and filling at points not far distant.

Summary.

These thirty-four sample cores show that *within the area near to these borings*, and embracing some of the most important parts of the upper harbor, *there is rarely more than a foot in depth of mud on top of the hard ancient blue clay floor of the harbor.*

The average of twenty-nine borings shows an average depth of 0.5 foot of material that might be classed as mud or shifting sand; and *the general effect of these borings, although not entirely conclusive, is to discredit the excessive amounts of shoaling indicated at some localities by a comparison of the ancient and modern soundings.*

Map of Dredging in Boston Harbor.

There is inserted opposite p. 386 a map that I have had compiled with much care, partly for use in locating the borings described above, and partly for showing the extent to which the present harbor channels are artificial.

On this map I have also sought to make the course of the deep natural channels plain and conspicuous by coloring the deep-water areas below the 30-foot contour in blue. On this map is also shown the location of each of the cross-sections upon which were made the current measurements described in Appendix No. 11, which follows.

Note concerning Survey of 1835, etc.

On examining the Perham map and the legislative report accompanying it, at the State House, Boston, I find internal evidence that, although made seventy-two years ago, it is the most accurate and complete map of the upper harbor ever yet made. The entire region was cross-sectioned in 100 foot squares, probably on the ice, and the depth measured at each intersection, and recorded on the map to tenths of feet.

The original note books have not been found, and it is possible that the fractions come in the tidal reduction.

It is hard to conceive of any possible means for this cross-sectioning except work on the ice; and the printed report to the Legislature shows much work was done in this manner, but does not state how much or what parts were surveyed from the ice. In those days there were no tugs and steamers passing constantly to break the ice.

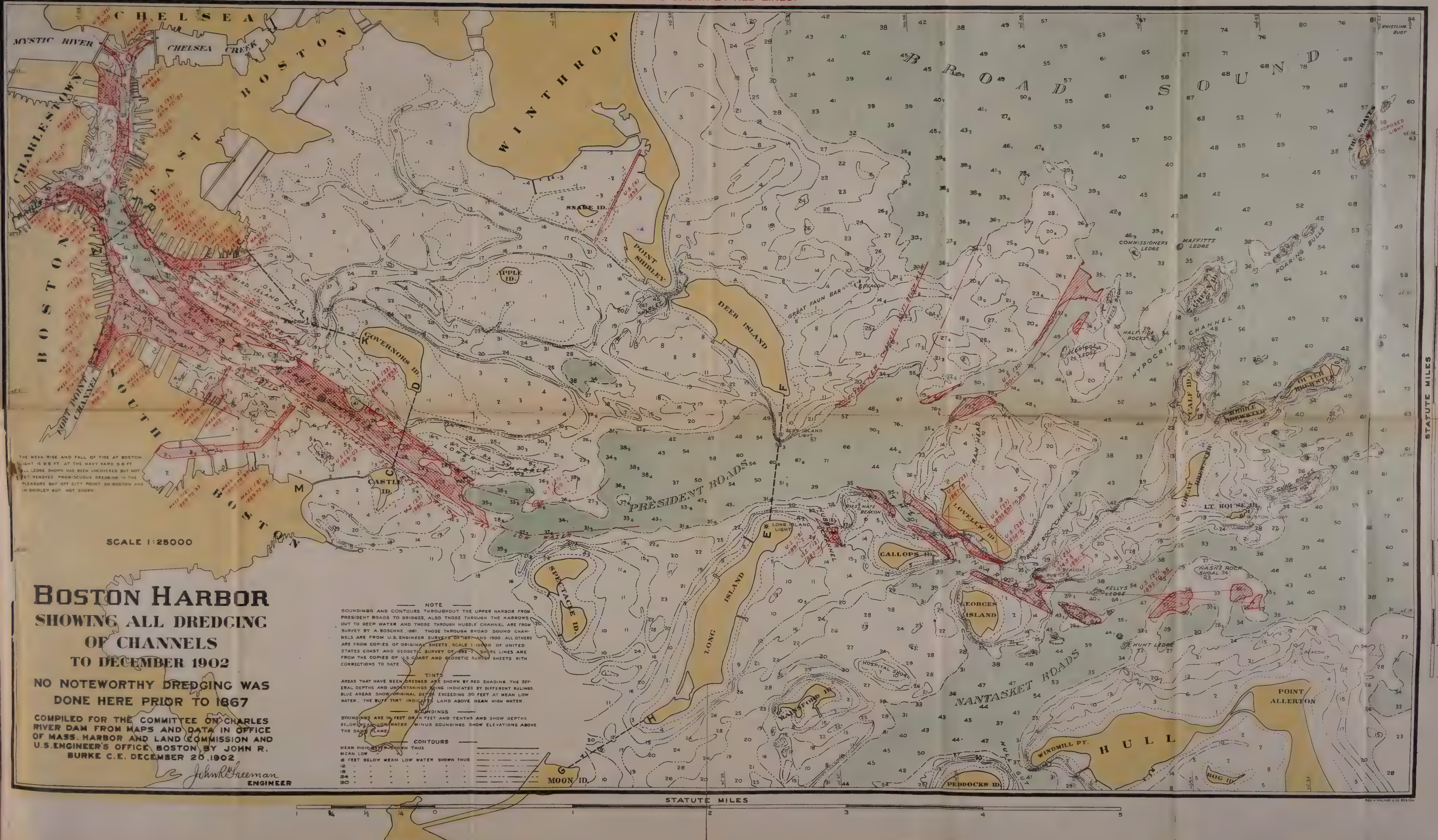
The survey of 1847 was mainly designed for consideration of the proposed South Boston flats improvement, and does not give harbor depths with frequency or precision. The Chesboro map of 1852 is also found meagre in detail, and useless for this particular study.

The Boschke survey of 1861 gives less frequent soundings than Perham's; they are irregularly spaced; the numerous cross-ranges ought to guard against serious error. The *plane of reference is not distinctly stated or defined by a bench mark*, but is assumed to have been low water at spring tides, or 2 feet below mean low water.

I personally examined old note books in attic of State House, and find the fractions of a foot shown on map came from the tidal reduction. Observations are recorded in fathoms and even feet, and evidently were mainly taken from a moving small steamboat.

The Low survey of 1892 had soundings not far from 100 feet apart, checked by frequent cross-ranges, apparently all taken from a moving boat. Plane of reference, mean low water. No bench mark quoted.

ALL DREDGING SHOWN BY RED LINES.



Appendix No. 11.

Measurements of Velocity of Currents in Boston Harbor.

Field work by W. E. Spear, C.E., and party.
Report by J. R. Freeman, *Chief Engineer.*

Reasons for These Measurements.

The chief reason was that, so far as could be learned, there had never been any accurate or complete measurements of the velocity of the water at the bottom of the channels, and obviously it is the bottom velocity that controls the scour.

The reports of the Advisory Board of United States Commissioners on Boston harbor, 1860 to 1865, contain, for that date, an admirably complete series of surface velocities measured at a great variety of locations in different parts of the harbor; but these were for showing the direction and speed of the current, — the "set and drift" affecting the movement of boats, scows, etc. This series of reports also contains a few measurements of the relative velocities at different depths, but none of them very near to the bottom.

Surveys prior to placing the metropolitan sewer out-falls at Moon Island and Deer Island comprised many measurements of the surface currents, but none of the velocities near to the bottom.

All of the few measurements of velocities at mid-depth or below that are found on record were made by the imperfect method of double floats, now nearly obsolete.

Taking all the available records of measurements of currents in Boston harbor up to the year 1902, they do not now appear complete enough to warrant many of the deductions that have been attempted from them.

It was claimed with great earnestness, by the opponents, at the hearings on the Charles River dam before the Board of Harbor Commissioners, in 1894, that one effect of the proposed dam would be a great injury to Boston harbor, and consequently to the commercial welfare of Boston; and it was then asserted, in repetition of certain fundamental statements in the voluminous reports on Boston harbor by the Advisory Board, written about forty years ago, that the origin and preservation of Boston harbor was due to the scour of the tidal currents, and that any lessening of the velocity of these currents would work great harm by causing or permitting shoaling of the ship channels. These reports were written at a time when the tendency was to attribute about everything in channel formation to scour, as necessarily the cause, because of lack of other simple explanation.

This suggestion, that shoaling would occur with lessened currents, necessarily involved the proposition that material for forming shoals was present in suspension during the whole or a part of the year, and prevented from settlement by the agitation due the current, or was

being rolled along and prevented from permanent deposition by the velocity existing at some stage of the tide; but no proof of the presence of such material in noteworthy quantity was offered.

A careful re-reading of all of the evidence printed in reports of these hearings of 1894 and 1902 fails to show that these statements regarding probable shoaling were anything more than opinions, based on the scant data of those early days of harbor engineering;* and, indeed, failed to show that they had so substantial a basis of observed facts as the contrary opinion presented by the Joint Board and its engineer, thirty years later, to the effect that the harbor currents in the channels frequented by ships were already too feeble to produce scour, and that there was not sufficient amount of silt or sand suspended in the water to produce any shoaling of importance, however slow the currents. *In none of these early studies is there any reference to the origin of the harbor from the geologist's point of view, but all channels are explained by scour of tidal currents.*

The very interesting report of Professor Niles, p. 540 of volume of evidence, shows that the development of this geological history has nearly all come to light since that time.

In this evidence of 1894 before the Harbor and Land Commission there was a remarkable absence of new data of actual measurements and precise observations; and in explanation of this is cited the insufficient funds available for carrying on investigations.

In the hearings of 1902 the opponents placed much less emphasis upon the possibility of injuring the harbor than at the hearings of 1894, and not one of the hydraulic or engineering experts retained by those opposed to the dam presented evidence to indicate that the lessening of these velocities would lead to any serious shoaling.

In the examination of experts before the Harbor and Land Commission, in 1894, much stress was laid upon this matter of velocity of the harbor currents, as, for example, in Marinden, p. 90; Whiting, p. 207; Stearns, pp. 498–501, 535; Mattice, p. 775; Bartlett, p. 873; also Abbott, p. 1004, etc.; and the Harbor and Land Commissioners, on page xvi of their report, say that *in order to answer understandingly the question of whether the cutting off of the tidal volume of the Charles can be done without injury to the harbor, a series of observations of the currents should be made;* and they urged this particularly on the ground that many changes in the tidal volume and channels had been made since the current measurements of forty-two years ago.†

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* That these were in the early days of American harbor improvement is illustrated by the fact that no dredging or systematic structural improvement of Boston harbor was begun on any noteworthy scale until after the war, or after 1865. It is also well to bear in mind the fact that the work of this United States Commission on Boston Harbor covered the period from 1861 to 1865, in which the war for the preservation of the Union was absorbing the chief thought and activity of the government service.

† These may be found in the fourth report of the United States Commissioners, p. 30, etc.

MEASUREMENTS OF CURRENTS BY UNITED STATES BOARD, 1861–65.

The following comprise all of the important notes concerning the velocities of currents within Boston harbor and on the method of measuring them that I have found in the series of ten reports by the United States Commissioners on Boston Harbor between the years 1860 and 1866. It is interesting when reading these old reports to note how almost every page breathes of tidal scour as the one possible force by which harbors are created and maintained.

In the fourth report, Boston City Document No. 62, year 1861, p. 7, it is stated that "many thousand systematic observations [on currents] have been made."

On page 22 it states that: "In the channels on either side of the lower middle shoal the flood drifts are respectively 0.73 and 0.58 miles per hour; while between these localities, upon the bank itself, we note, by simultaneous observations, very feeble horizontal movement. The ebb, in a similar manner, runs 0.26 and 1.18 for the channels, while the intermediate stations upon the shoal give us no measurable velocities."

Fourth report, p. 22: With reference to the narrows in the main ship channel, near Fort Warren, it is stated that part of the then main ship channel in the immediate

Moreover, the conclusions as to the preponderance of the scouring force of the ebb tide, dwelt upon so much in the reports between 1861 and 1865, now appeared without substantial support from actual measurement, and contrary to probability.

Therefore I sought to determine: —

(*a*) The actual maximum velocity at the bottom of the harbor, available for producing scour, at representative points in the main ship channels and anchorages.

(*b*) The relation of the velocity of the current on the bed of the harbor to the velocity near the surface. This was desirable for showing in how far the previous observations on surface currents were applicable to the problem of scour.

(*c*) The velocity of the current from hour to hour or from minute to minute throughout the entire cycle of the tide, in order to learn the duration of the scouring forces, and whether there was any such preponderance of the ebb over the flood, in duration of scouring force, as had been claimed.

(*d*) The relation of the velocity in various parts of the channel to the mean velocity of the whole cross-section, so that, knowing the volume of the tidal prism above any given cross-section from its surface, as shown by the charts, and knowing its depth as shown by the tide gauge and the charts, and having computed its mean velocity past the section in question, we could find approximately what its scouring velocity was on various portions of the bed.

Scope of Observations.

For the site of the velocity measurements I selected four principal cross-sections of the tidal currents, after a study of the harbor charts.

(1) The Charles estuary section was near the proposed dam site. (We made but few measurements here, — merely enough to test the working of our apparatus, and to obtain some idea of the currents that would have to be resisted in closing these channels by a dam.)

(2) The ferry section was at the section of smallest area in the narrow channel, between Boston and East Boston.

(3) The Governor's Island section was at the section of smallest

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neighborhood of the narrows line is the scene of continual whirls and eddies, which, although not violent, are bewildering to the navigator.

Fourth report, p. 30: In Table No. 1 there are presented statements of the strength of current at fifty-one different stations, scattered all the way from east of Boston lower light and off Nantasket beach to the south, and between the Graves and Nahant on the north, and thence up the harbor to the mouth of the Charles River. The time of the turn of the tide in relation to the moon's position is given for each station; also the maximum velocity and direction of the flood and the ebb and the duration of the current; also the *resultant of the "scouring forces"* for one tidal day measured *at the surface*. For most of the stations this resultant is also given for various depths.

In tables Nos. 2 to 6 are presented statements of the comparative velocities of the current at different depths at five different stations, and drawings are presented showing these relative velocities.

In the fifth report of the United States Commissioners, Boston City Document No. 63, for the year 1861, on pp. 46–50, is presented a repetition of the data on current for various stations in the harbor given in the preceding report, accompanied by similar data for eight additional stations.

In the seventh report of the United States Commissioners, Boston City Document No. 33, year 1864, in an appendix presented by Henry Mitchell, assistant, United States Coast Survey, on pp. 68, 69, are presented certain comparisons of the velocity of the current and the rise of the tide per hour for stations on the Broad Sound channel, selected from some of his observations made for the city of Boston in the year 1860; and on p. 71 of the same report Mr. Mitchell describes his method of observation, as follows: —

First, referring to his report on the method of float measurement given in the appendix

effective area between Governor's Island and Castle Island, on what may be regarded as the dividing line between the upper harbor and the lower harbor.

(4) The outer section was between Deer Island and Long Island head.

Several small subsidiary sections were also partially measured; namely, Shirley Gut, the Moon Island channel, the Bird Island channels, and the section between Castle Island and South Boston.

It will be observed, on examination of the map of Boston harbor, inserted at p. 386, that these three harbor sections are the three cross-sections of least area found as the harbor widens going seaward, or they are what in river hydraulics would be considered as the "controlling sections."

It is on these sections that the velocities are greatest and the scouring effect most intense.

After having determined the relation of the velocity in different parts of these controlling sections from hour to hour, from side to centre and from top to bottom, we can, by proportion from the relative areas of cross-section shown by the harbor survey charts at other localities intermediate between the controlling sections, approximate to the bottom velocity at any point in question, due regard being given to obstructions and eddies.

Because of taking so many observations at each of these four sections, I was unable to occupy nearly so large a number of stations as are named in the fourth report of the United States Commissioners, Sept. 28, 1861, p. 30, etc.; and, as a matter of general scientific interest, I

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to the report of the superintendent of the United States Coast Survey, 1859, he states that in these measurements in Boston harbor the floats consisted of cylinders, instead of spheres. The locality then under discussion was the Fort Point channel, but presumably the method is the same that he used in other cases. He says: —

"Motions below the surface were measured by comparing velocities of free floats with those of connected bodies hanging perpendicularly, one below the other, and connected with a fine cord. The objection to the use of spheres arose from the difficulty in estimating, in the sub-current apparatus, the differences in their effective areas. In the case where the velocities and directions both varied between the surface and substratum, I had been obliged to construct a long formula when the floats offered different surfaces, — the upper sphere of course protruded somewhat from the water. Using cylinders, I made a conical top to the one designed for the surface, and could therefore sink it to the base of this cone. In this way equal areas were maintained. Moreover, I contrived to pass the "connecting line" up through a tube in the floating cylinder, so as to be able, without taking the apparatus from the water, to alter its draught. . . . When the observations at ten feet depth had been made, two or three minutes sufficed for altering the floats to five feet, or any other depth."

He describes the measurement of time of transit of these floats as follows: —

"Three points were chosen in a line crossing the stream at right angles, and these were alternately occupied by a boat. In this boat I went myself, taking, as my assistant for arranging the current apparatus, one of my aids. Two other aids were provided with sextants, and stationed at prominent points on the neighboring piers. As our floats left the boat a signal was given, and the two observers on shore took simultaneous angles upon it; after a lapse of thirty seconds another signal was given, and another set of angles measured. The positions given by these angles were checked by the count of the log-line. My assistants had been long practised in nice work of this kind."

The next reference to velocity measurement is found in the tenth and final report of the United States Commissioners, Boston City Document No. 50, 1866: —

"If we glance at a chart of Boston harbor, we observe that it consists of three divisions, — a roadstead, and two grand lagoons or basins. Nantasket Roads from the head of Quincy Bay to the sea, with the Hull basin on the one hand and the grand lagoon above Long Island on the other, constitute Boston harbor. The communications with these grand divisions are scoured to the utmost limit that the materials forming their beds and banks will allow, by the vast bodies of tide water pouring through them in the struggle to preserve an equilibrium between the interior basins and the sea. If we compare the outer entrance to any one of these divisions with any subsidiary channel leading to a minor basin within, we find that the former is the more ample waterway; and the conclusion is obvious that this superiority is in the main due to the greater scour to which it is subjected in its service as a tidal avenue. Let us, for instance, take the Hull lagoon; how insignificant are the creeks leading to the Weymouth and Hingham reservoirs, compared with the noble channels on either side of Peddock's Island, — channels which not only fill and drain the tributary basins we have mentioned, but the

would have been glad to carry these observations very much further, but felt constrained to leave this work for other fields so soon as enough data to answer our main question had been secured.

The Instruments and Methods of Measurement used.

The instruments mainly relied upon were Ritchie-Haskell direction current meters, of the form now used by the United States Coast Survey and by the United States Engineers, for the study of harbor currents. A part of the time we had three of these in use simultaneously, and also a Fteley and Stearns current meter and an Ellis current meter with an electric circuit. The Stearns meter was used on a staff for velocities near the surface; the Ellis meter and two of the Ritchie-Haskell meters were suspended on wire cables and weighted at bottom end; the other Ritchie-Haskell meter, which had been received without a wire cable like those provided for the other meters of that type, was hung on a sash cord, with a weight of 60 pounds of lead attached to bottom of meter, in the same manner as the other Ritchie-Haskell meters. The Ellis meter was weighted at bottom with 40 pounds of iron. It will be noted that we used very heavy weights and thin cables in the effort to hold the suspending cable near to the vertical, and also in order to lessen oscillation. In the high velocities of the deep Deer Island channel still heavier weights would have been preferred, save for the hard labor of frequently pulling the meters to the surface, in order to make sure of their freedom from eel grass or other rubbish.

Meter No. 5, United States Coast and Geodetic Survey, was loaned for this work by the superintendent of the Coast Survey, through

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tide of the great lagoon itself. We never glance at a chart of Boston harbor without being impressed with the natural advantages of this particular locality. Here is a fine anchorage ground, protected from wind and sea, with two deep entrances from an outer roadstead; and these entrances, as well as the roadstead itself, are kept free by tidal currents, especially, without aid from back-waters.

"Nantasket Roads is the conduit for the tide of more than one-half of Boston harbor, and the Broad Sound channel for the remainder; unless we regard as worthy of consideration the Black Rock channel, which is traversed by a small but rapid stream which crosses the main ship channel, and co-operates, as far as may be, with the stream of Nantasket Roads in the filling and draining of Quincy Bay.

"It is a very remarkable circumstance that the main ship channel here is traversed by no current along its course; and we have tried in vain to conceive by what disposition of forces it was first created. That it must once have been dug out by a tidal stream would seem evident from the form of its bed and banks.

"The upper harbor — the portion above Castle Island — is too near the head of tide water to be traversed by a great volume of ebb and flood; the evidences, therefore, of strong running forces are only to be met with at its contractions. It is, however, a receptacle of both tidal and river waters, and the latter bears in amount a larger ratio to the former in this than in any of the other portions of the harbor that we have named; yet here it is small, — so small that, without the co-operation of tide water, it could not maintain a navigable channel to the sea.

"The main channel of the upper harbor of Boston is chiefly dependent for its depth and width upon its service as the avenue of supply and drainage for the basins of the Charles and Mystic rivers and Chelsea Creek. Were these reservoirs closed, the larger part of this main artery would, in course of time, cease to exist; for it is but the trench dug through the yielding bed of the harbor by the passage to and fro of the river and tidal waters."

On p. 51 of the tenth report a statement is given as to the measurement of the velocity of the current at the mouth of the Charles River, about a quarter of a mile westward of the United States dry dock. It is stated that: "from observations extending through an entire tidal day, the ratio of inflow to outflow was found to be as 8:10; and the mean hourly velocity of the river current, five hundredths of a mile. Our method of computing the rate of river current was as follows: The hourly observations made with apparatus drawing eighteen feet were plotted in curves upon profile paper, the flood above and the ebb below an assumed axis. Through the determined points a smooth curve was drawn, and new ordinates for equal intervals of time (fifteen minutes each) were taken out (those above the axis receiving the plus, and those below the minus sign), and the algebraic mean of these ordinates was recorded. This mean was found to be, as we have said, five hundredths. By this process the variable tidal flowage is eliminated, and there remains only a constant which must represent the velocity of the river at this point as it would be if there were no tides."

Then we have a quotation of Dubuat's statements of the velocity required to remove clay fit for pottery, sand, etc., *and no other authority than Dubuat is quoted.*

the kindness of Lieut.-Col. W. A. Jones, U. S. A., now of the light-house service.

Meter No. 5, United States Lake Survey, was loaned by the chief of engineers for this work, from the United States Lake Survey Office at Detroit, Mich.

Meter No. — was also loaned by the chief of engineers, and came from the United States engineer office at Savannah, Ga.

Of the two vanes furnished with the Ritchie-Haskell meters, that known as the "wheel for low velocities" was used throughout these measurements except in the few measurements at the Charles River estuary section.

The first two instruments, which were used to determine direction as well as velocity of the currents, were thoroughly overhauled and inspected by the makers, Ritchie & Sons, Brookline, Mass., immediately prior to the work. Great care was used in their manipulation, and each of the four electrically connected meters was promptly pulled to the surface and inspected for eel grass or other obstruction whenever an important change in speed was noted.

For counting the revolutions of the meter the recording attachments were not relied upon; but the click of an electric sounder worked by the circuit breaker in the axis of the instrument was counted by ear, while the eye rested on a stop watch, — for the ear is quick to detect any irregularity or change of speed.

Rating or Calibration of Instruments.

The Coast Survey instrument and the Savannah instrument were rated just before these experiments, and all the instruments were rated with great care as soon as the observations were finished. This work was done under favorable conditions at Lawrence, Mass., at the lower locks in the north canal, where a rating station is maintained by Mr. R. A. Hale, principal assistant engineer of the Essex Company, to whose courtesy we are indebted for the use of these facilities. The meters were each in turn attached to a wheeled truck, which runs on a track placed on the inside edge of the ice boom, just up stream from lower end of the canal, in such a way that the meter could be made to travel at different speeds, at a depth of about two feet in the quiet water inside of the boom. Since, in the Ellis and the Ritchie-Haskell meters, the arrangement of the electric contact makes it impossible to accurately determine the fractions of a revolution, it was necessary to adopt some other method of rating than that used with meters of the Fteley and Stearns type, which are made to record tenths of a revolution, and which when rated are usually run over a fixed distance and the time and number of revolutions observed.

For rating these meters a scale was marked upon the track immediately under the truck carrying the meter, on which was placed an index whose position could readily be read upon the scale. The time and position of the truck were noted at the instant of occurrence of a click of the velocity recorder near each end of the space over which the truck was driven at a uniform speed, and from these observations of distance and time the actual rate of motion and the corresponding number of revolutions of the meter per minute were computed.

To make sure of avoiding error from slight motions of water in this pool, due to wind and to leakage through the waste weir at end of canal, the direction of motion was reversed in successive observations.

In order to secure a more uniform motion than can be obtained by walking, for the slow velocities that approached the minimum speed at

which the meter wheels would revolve, the expedient was devised of drawing forward the small wheeled truck from which the meter was supported, by means of a small, strong, flexible wire, that was hauled in by a little windlass, the number of revolutions of which in a given time could be regulated at will.

A great number of points on each rating curve were observed; and, notwithstanding the studied irregularities of distribution of successive observations, the plotted observations fall in line along the rating curves remarkably well, considering the low velocities used. For example, the mean deviation of the plotted observations from the curve of rating of the Savannah meter was 2.3 per cent.

The great number of observations and their excellent general agreement make it probable that the error of rating was well inside 1 per cent.

Particular attention was given to determining the rates at extremely low velocities. The limiting minimum velocities measurable with the Fteley and Stearns and the Ritchie-Haskell meters (wheels for low velocities) were found to be about 0.2 foot per second; while with the Ellis meter, with electric attachments, in which there is more axial friction, it was not found possible to accurately measure velocities less than about 0.5 foot per second.

Boats and Positions.

We tried to so use a boat as to introduce the smallest practicable disturbance of velocities in the cross-sections, and tried to use a small boat. Our first measurements, those in the Charles, were from an 18 foot gasolene power dory; but on taking this to the upper harbor it was found that, in its heavily loaded condition, the waves from passing ferry boats would wash over the side. An open gasolene launch of about 1.5 feet draft, 4.5 feet beam and 27 feet over all was next tried, and served excellently for all the earlier series of measurements in which only a single meter was used.

The launch was worked into the desired position on range by running across the section against the tide, first dropping a stern anchor a little below the range and to the windward of the desired position, then, when sufficiently above range, the engine was reversed, the bow anchor set, and the boat worked into the desired position. At first it was held by a bow anchor and two quarter anchors, with the lines drawn fairly taut; but it was found that by taking advantage of wind and tide one of the quarter anchors could commonly be dispensed with. The exact location of each position was located by sextant angles to prominent points about the harbor, whose position was kindly given us by Mr. F. W. Hodgdon, chief engineer of the Harbor Commission.

While working, often anchored in the "fair-way," with a boat of this small size, some of the large incoming and outgoing craft paid little attention to our desire not to be disturbed. To escape being run down, anchor lines were kept buoyed and sometimes had to be slipped in a great hurry; and, after several uncomfortably close calls and after shipping the crests of some waves in the broad reaches of President Roads, it was concluded that for safe work in the lower harbor in November weather a larger boat was essential. The steam yacht "Eleanor" was next engaged, and found to be admirably adapted for the work in hand. This boat was 62 feet long over all, 54 feet on water line, 5 feet draft and 10 feet beam, and gave ample space for manipulating five or more meters at once, and for remaining out on station over night, while the gasolene launch was used as a

tender and for setting the quarter anchors. Even with this larger boat the necessity for our anchoring in mid-channel was not fully appreciated by passing ship masters; and, although we flew a bright red flag, 5 feet wide and 8 feet long, with the word "Survey" in white letters, each a foot high, we narrowly escaped being sunk through the stupid carelessness of the master of a Rockport granite schooner, who threw his helm hard-a-starboard just in season to avoid doing anything worse than raking us with her main boom, carrying away both our masts and standing rigging, and smashing smoke-stack, pilot guard, binnacle, etc. This accident did not suspend the day's observations.

Having the boat once in position parallel to the current, it was intended during the second series of current measurements to retain the same position through the cycle of a tide; but our light quarter anchors were not always heavy enough to hold the boat stern on after the tide had turned, so, while the large bow anchor held fast, the boat was sometimes allowed to swing the cable's length with the change of tide, and the quarter anchors were then reset.

At the East Boston ferry section we were prevented from taking exactly the position desired, by the presence of a large ocean steamer and by a large coal schooner anchored on our range; but much care was given to so placing our boat that it should be where the possible disturbance from these anchored ships should be either nothing or at a minimum. Sextant locations at frequent intervals were made at each position occupied.*

Preliminary Series.

In the first series of observations from the smaller boats only one meter was in use at a time. Our first object was to observe the relation of velocities at different depths and at the bottom to the surface velocity. The boat was anchored and located by sextant angles, the meter lowered over the side and suspended at the desired depth, and after time given for its inertia to be overcome, the revolutions were counted by stop watch for about one minute. The meter was then raised or lowered to another position, and again counted for about one minute. While moving to the various points on the curve care was taken to break up the continuity of the series, and thus reveal any periodic error, by moving to alternate depths in raising or lowering, and occupying the alternate stations on the return. After the boat party became handy with the tackle, it ordinarily took about thirty minutes to complete a vertical section with twenty observations.

The results of this first series of measurements do not differ materially in the relations of velocity at different depths from that obtained by the more complete series with five meters in use, shown on the following sheets, and the plotted observations and curves of the first series are therefore not reproduced here.

The horizontal distribution of velocities was similarly measured, point by point, at about one-third of the total depth, completing the section across between the ferries within sixty minutes, and that between Governor's Island and Fort Independence in about one hour and thirty minutes. At the ferries section and elsewhere, as far as time permitted, the horizontal distribution of velocities was determined at

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* After working up the Fort Independence-Governor's Island section, it was found that the position taken for the "tide cycle series" was perhaps not the best that could have been chosen for measuring the volume of tidal flow; but there was not time to repeat, and for the main purpose of determining bottom velocity at a critical point it appears all right.

the first third, at the middle and at the last third of the ebb and flood tides.

These horizontal sections would have been made in fuller detail had time allowed, but appeared sufficiently full for the problems immediately in hand.

SECOND SERIES, WITH FIVE METERS.

This second series served the double purpose of giving simultaneous observations at various depths, and of showing the variations from hour to hour or from minute to minute through the tidal cycle, and thus to show whether or not there was any such marked predominance in duration and scouring force of ebb over the flood as had been inferred from the observations of 1861. The meter nearest the surface was read directly by taking it out of water after a two-minute run, once in each five minutes. The register wires from the four meters having electric counters were led to the boat's cabin, where the two observers, each attending to two counters, switched first one and then the other into circuit with the bell or buzzer, and, with stop watch in hand, counted the clicks of the sounder, and thus found the number of complete revolutions of meter that took place in about two minutes. The hour and minute of each set were also recorded.

A fourth assistant took sextant observations, observed velocity and direction of wind, and took a few thermophone observations or helped clear the meters when anything went wrong. Any irregularity of electric contact or any fouling of a meter apparently was revealed at once by the changed beat of the sounder; and that meter was at once pulled to the surface by the boatmen and made right by the chief of party, W. E. Spear, C.E.

The meter nearest surface was used at depth of two and three feet below the surface, it being impossible in the choppy seas of the lower harbor to keep the meter continuously immersed under proper conditions for accuracy at a less depth. The other meters were distributed in the vertical section between the surface and the bottom, the lower meters being placed nearer together than those nearer the surface; for it is near the bottom that the greatest differences in velocity are found, and the bottom velocities are more important than those near the surface for the solution of the problems presented.

The depth of immersion was measured off from tags on the suspending cable. The inclination of the cable in the stronger currents was measured and a correction applied in obtaining the depth.

In order to make sure of the position of the lowest meter in relation to the bottom, this was provided with a wooden shoe about 28 inches long by 14 inches wide, attached to the bottom of the 60-pound lead weight, and the line was slacked away until this rested on the bed of the harbor. This worked fairly well in all the observations on the Governor's Island section; but at the Deer Island section the strong current prevented placing this large shoe properly, and the instrument, therefore, had to be first lowered until its lead weight touched bottom and was then raised a foot or two, this distance and depth being recorded.

At the turn of the tide, for about an hour, the velocities were so slow that these instruments could not record them. Therefore, at such times, so far as practicable, we measured the average velocity within 10 feet of the surface by means of a square pine rod 1½ inches square, 10 feet 2 inches long, having a sheet lead sinker attached to its lower end.

Care was taken to avoid any disturbing effect of our own boat upon the distribution of velocities, by locating the meter for surface velocities as far forward as possible upon the overhanging prow; the meter next

below the surface was set just astern of the first. The deepest meters were about amidship. All of the latter were suspended from the davits, well clear of the side; and it is my opinion, based on much experience in measurement of velocities elsewhere, and after observing the conditions here, that the proximity of our boat introduced no appreciable error into the velocity measurement.

Height of Tide.

The time of each observation was noted, for determining its relation to the tidal cycle; and to aid us in this work the commandant of the Navy Yard very courteously placed the record sheets of the self-recording tide gauge at our service.

I had procured two other recording tide gauges, intending to use one at Deer Island light and another at Harvard bridge, for measuring the progress of the tidal wave and the simultaneous difference of elevation, or slope from one station toward the other, which alone produces the velocity, but found no time to go into this interesting detail.

Soundings were made by the meter cable and its 60-pound weight to make sure of the relative position of meter and bed of channel.

Wind and Weather.

The weather was uncommonly fine for the season of the year. Much of the time the wind was very gentle; occasional measurements of its velocity were made by means of a Byram anemometer, and its direction also noted.

Velocity of Wind in Boston Harbor during Current Meter Measurements observed mainly with Byram Anemometer No. 2464 at Survey Boat, supplemented by Observations at U. S. Weather Bureau on Post-office Building, Boston.

Date 1902.	Time of Wind Observations.		Observations by Anemometer.		Observations on Post-office.	
	From —	To —	Direction.	Velocity (Miles per Hour).	Direction.	Velocity (Miles per Hour).
Oct. 24, . .	10 A.M.	12 M.	S. W.	12.7	S.	15
Oct. 24, . .	4 P.M.	5 P.M.	S. W.	7.6	S. W.	12
Oct. 27, . .	9 A.M.	10 A.M.	S. S. W.	9.3	S.	12
Oct. 27, . .	10 A.M.	12 M.	S. W.	10.2	S. W.	14 to 16
Oct. 27, . .	12 M.	4 P.M.	S. W.	7.1 to 10.6	S.	13 to 16
Nov. 14, . .	6 P.M.	7 P.M.	W.	5.1	S.	6
Nov. 14, . .	11 P.M.	12 Mdnt.	W.	4.8	S. W.	9
Nov. 15, . .	12 Mdnt.	1 A.M.	(W.)	7.6	S. W.	7
Nov. 15, . .	4 A.M.	5 A.M.	(W.)	11.9	S. W.	10
Nov. 15, . .	1 P.M.	3 P.M.	S. W.	10.6 to 14.4	S. W.	14 to 15
Nov. 15, . .	6 P.M.	8 P.M.	S. W.	7.5	S. W.	13 to 15
Nov. 17, . .	2 P.M.	6 P.M.	E.	7.1 to 8.2	N. E.	11 to 13
Nov. 17, . .	7 P.M.	8 P.M.	E. N. E.	9.2	N. E.	10
Nov. 17, . .	8 P.M.	12 Mdnt.	E.	4.7 to 6.7	N. E. to N.	7 to 9
Nov. 18, . .	12 Mdnt.	3 A.M.	–	–	N.	8 to 9
Nov. 18, . .	1 P.M.	6 P.M.	–	–	E.	15 to 17
Nov. 18, . .	6 P.M.	12 Mdnt.	–	–	N. E.	12 to 15
Nov. 19, . .	12 Mdnt.	5 A.M.	–	–	E. to N. E.	12 to 15

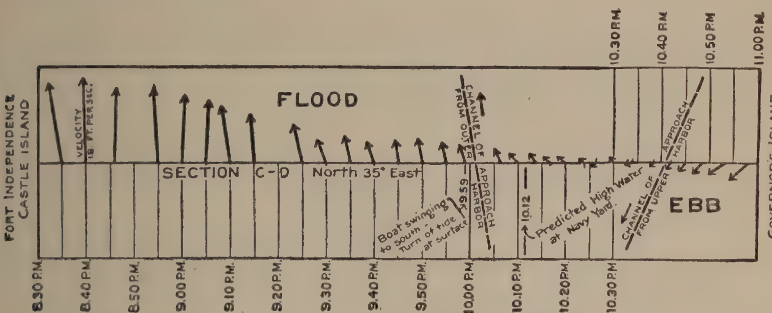
Measurement of Direction of Deep Currents.

We were mainly unsuccessful in this, for, although this Ritchie-Haskell instrument is designed especially for this purpose, it was hard to keep the direction attachment in good order. We sent the instruments back to the maker several times, and the direction index would work beautifully on the office table, but when set under 30 to 60 feet of salt water it gave much trouble. The cause of the trouble proved to be due to corrosion of the delicate mechanism in the body of the meter by the salt water that leaked in under the pressures, due to great depths to which the meter was immersed. This corrosion went so far that some of the parts in the body of the meter had to be replaced. For two days the expert mechanician from the maker's workshop, who is most familiar with this instrument, made one of our party, and tried to keep the direction index working.

The exact direction of these currents was, after all, a matter of secondary importance for the study of scour; and, although we obtained a few good observations on direction, we finally gave up the continuous direction tests of the deep currents, to avoid serious interference with the velocity measurements.

The direction at and near the surface was of course easily seen at all times by the floating material and the strain on our anchor lines, and at the Governor's Island section was shown by the inclination of the channel spar buoys. At about the time of slack water, when the tidal current was too feeble for accurate observation by the meters, deep floats, consisting of wooden rods 10 feet 2 inches long, immersed 10 feet by weighting with sheet lead wound about the lower portion, were used, and showed the mean direction of the upper 10 feet.

A sample set of observations that we obtained with the direction meter is given below.



SECTION C-D FORT INDEPENDENCE BOSTON HARBOR.
Direction of Tidal Currents at 3/10 of Total Depth above Bottom.
Before and after High Water November 14, 1902

Note. — Direction and length of arrows indicate direction and velocity, respectively, of current at the given time. Scale of velocity: ¼ inch in length of arrow = 1 foot per second.

This was observed on November 14, on the Fort Independence station.

At all times, excepting within fifteen to thirty minutes of the turn of the tide, the currents were straightforward, and, so far as observed, were approximately parallel to the axis of the approaching stream, or without eddies near the plane of measurement.

Relation to Velocities at Mean Range of Tides.

It is obvious that the velocities at a given station will be much greater at spring tides than they will at the time of mean tides. The relation of our various series of measurements to the conditions existing at tides of average height is shown by the following table. In the ratio presented in the eighth column of this table no account is taken of the fact that the volume of the tidal prism may not be exactly proportional to the height of the tide; for, with an extremely high range of tides, it is probable that the spreading out over the marshes at high water absorbs a noteworthy volume, which is not offset by the uncovering of flats at extreme low water. Neither was it attempted, when computing this ratio, to allow with any great precision for the fact that in the wedge-shaped estuaries the momentum of the current forces the water at various points to varying distances above the level of mean high water at the Navy Yard, or to allow for the fact that the water surface of the tidal harbor and estuary is not plane or level, because of the measurably slow advance of the tidal wave. A very rough approximation to this was, however, attempted.

To have determined all these attendant minor phenomena with precision would have required more time than was available, and several tide gauges at different locations would have been necessary. It is believed that the errors introduced by these approximations are not large enough to be of material influence in the present discussion.

Table showing Time, Character and Location of the Current Meter Measurements of the Tidal Currents in BOSTON HARBOR AND CHARLES RIVER *and the Relation of Tide when these measurements were made to the Mean Tide.*

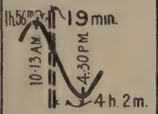
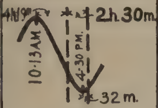
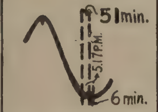
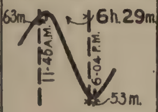
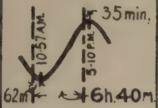
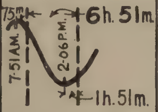
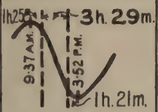
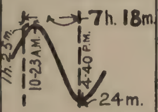
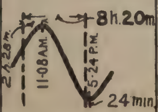
Date 1902	Time of Velocity Measurem't From	To	Stage of Tide	Total Range of this Tide at Navy Yard above M.L.W. From El.	To El.	Feet	Ratio of this Range to Mean Range of 9.8 ft.	Kind of Velocity Measurement. Single Meter or Five Meters at Single Points at varying depths.	Locality of Section of Velocity Measurement.
Oct. 16.	P.M. 12.09	P.M. 12.28		10.48	-0.60	11.08	1.13	Point measurem'ts in Vertical plane.	CHARLES RIVER Draw Pier of Harvard Bridge
Oct. 16.	P.M. 2.32	P.M. 5.02		10.48	-0.60	11.08	1.13	Point measurem'ts Two Vertical planes.	600 feet above Craigie Bridge
Oct. 17.	P.M. 4.20	P.M. 5.11		10.88	-1.10	11.98	1.22	Point measurem'ts Two Vert. planes.	600 feet above Craigie Bridge
Oct. 18.	A.M. 10.42	P.M. 5.11		11.20	-1.50	12.70	1.30	Point meas'm'ts in Vert. planes and at one third depth across channel.	600 feet above Craigie Bridge
Oct. 24.	A.M. 9.55	P.M. 4.35		9.83	0.80	9.03	0.92	Point meas'm'ts in Three Vert. planes	BOSTON HARBOR Ferry Section A-B Old "Section 10" betw'n East Boston Ferries
Oct. 27.	A.M. 9.06	P.M. 3.57		9.98	0.25	9.73	0.99	Point meas'm'ts in Three Vert. planes.	Ferry Section A-B.
Oct. 29.	A.M. 11.02	P.M. 2.31		10.48	-0.84	11.32	1.16	Point meas'm'ts at 13 feet depth across channel.	Ferry Section A-B.
Oct. 30.	A.M. 8.58	P.M. 4.16		10.02	-1.10	11.12	1.13	Point meas'm'ts at one third depth across channel.	Ferry Section A-B.
Oct. 31.	A.M. 8.40	P.M. 5.00		10.32	-0.90	11.22	1.14	Point meas'm'ts at one third depth across channel.	Ferry Section A-B

Table showing Time, Character and Location of the Current Meter Measurements of the Tidal Currents in BOSTON HARBOR AND CHARLES RIVER *and the Relation of Tide when these measurements were made to the Mean Tide.*

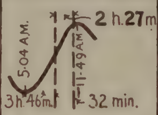
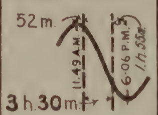
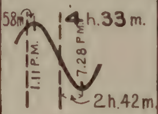
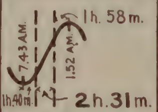
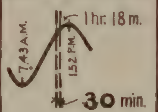
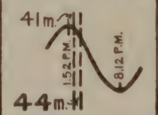
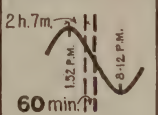
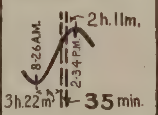
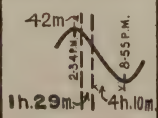
Date 1902	Time of Velocity Measurem't From	Time of Velocity Measurem't To	Stage of Tide	Total Range of this Tide at Navy Yard above M.L.W. From El.	To El.	Feet	Ratio of this Range to Mean Range of 9.8 ft.	Kind of Velocity Measurement. Single Meter or Five Meters at Single Points at varying depths.	Locality of Section of Velocity Measurement.
									BOSTON HARBOR
Nov. 1.	A.M. 8.50	A.M. 11.17		10.40	0.03	10.37	1.06	Point meas'mts one third depth across channel.	Ferry Section A-B.
Nov. 1.	P.M. 12.41	P.M. 4.11		10.40	-0.65	11.05	1.13	Point meas'm'ts in Vert. plane.	Ferry Section A-B.
Nov. 3.	P.M. 12.13	P.M. 4.46		10.38	0.48	9.90	1.01	Point meas'm'ts one third depth across channel.	Fort Independence Section C-D.
Nov. 4.	A.M. 9.23	A.M. 11.54		10.08	1.02	9.06	0.93	Point meas'm'ts one third depth across channel.	Fort Independence Section C-D.
Nov. 4.	P.M. 12.04	P.M. 12.34		10.08	1.02	9.06	0.93	Point meas'm'ts at one third depth across channel.	Marine Park Channel.
Nov. 4.	P.M. 2.33	P.M. 3.17		10.08	0.50	9.58	0.98	Point meas'm'ts one third depth across channel.	Ft. Independence Section C-D.
Nov. 4.	P.M. 3.59	P.M. 4.59		10.08	0.50	9.58	0.98	Point meas'm'ts in Vert. plane.	Ft. Independence Section C-D.
Nov. 5.	A.M. 11.48	P.M. 12.23		9.70	1.46	8.24	0.84	Point meas'm'ts at one third depth. across channel.	Ft. Independence Section C-D.
Nov. 5.	P.M. 3.16	P.M. 4.45		9.70	1.70	8.00	0.82	Point meas'm'ts one third depth across channel.	Bird Island Section J-K.

Table showing Time, Character and Location of the Current Meter Measurements of the Tidal Currents in BOSTON HARBOR AND CHARLES RIVER *and the Relation of Tide when these measurements were made to the Mean Tide.*

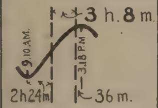
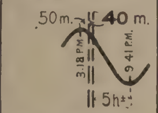
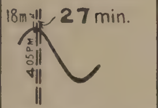
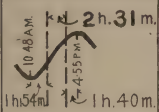
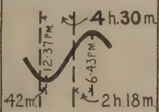
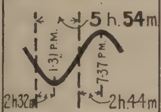
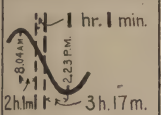
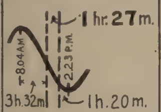
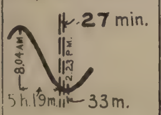
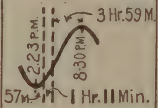
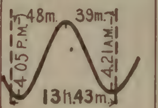
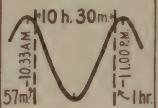
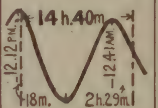
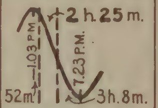
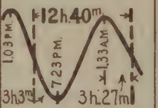
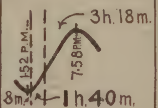
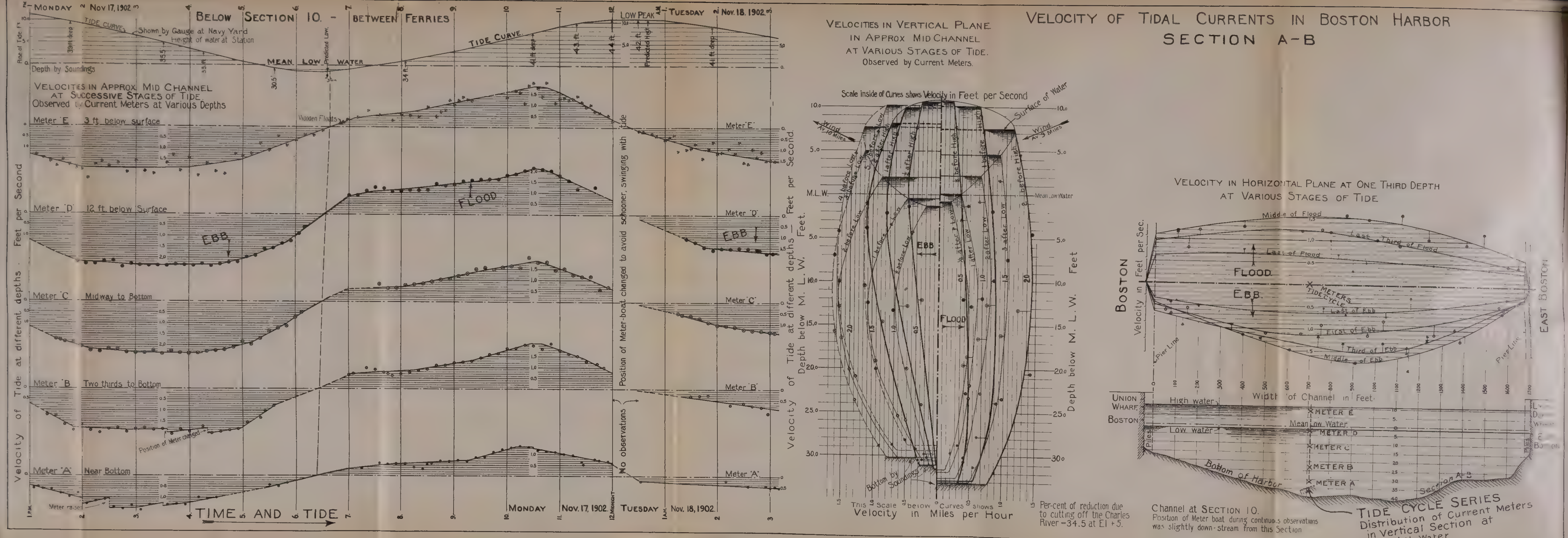
Date 1902	Time of Velocity Measurem't From	Time of Velocity Measurem't To	Stage of Tide	Total Range of this Tide at Navy Yard above M. L. W. From El.	To El.	Feet	Ratio of this Range to Mean Range of 9.8 ft	Kind of Velocity Measurement. Single Meter or Five Meters at Single Points at varying depths	Locality of Section of Velocity Measurement.
									BOSTON HARBOR
Nov. 6.	A.M. 11.34	P.M. 2.42		9.42	1.70	7.72	0.79	Point meas'm'ts at one third depth across channel.	Fort Independence Section J-K.
Nov. 6.	P.M. 4.08	P.M. 4.48		9.42	1.15	8.27	0.84	Point meas'm'ts at one third depth across channel.	Fort Independence Section C-D.
Nov. 7.	P.M. 4.23	P.M. 4.50		9.1	1.2	7.9	0.81	Point meas'm'ts in Vert. plane.	Fort Independence Section C-D.
Nov. 8.	P.M. 12.44	P.M. 3.15		8.9	2.0	6.9	0.70	Point meas'm'ts at one third depth across channel.	Deer Island light. Section E-F.
Nov. 10.	A.M. 11.55	P.M. 4.25		9.00	1.86	7.14	0.75	Point meas'm'ts in Vert. plane.	Deer Island Light Section E-F.
Nov. 11.	A.M. 11.01	P.M. 4.53		9.22	1.4	7.8	0.80	Point meas'm'ts in Vert. planes.	Deer Island Light Section E-F.
Nov. 12.	A.M. 10.05	A.M. 11.06		9.82	0.25	9.57	0.98	Point meas'm'ts in Vert. planes.	Marine Park Channel.
Nov. 12.	A.M. 11.36	P.M. 1.03		9.82	0.25	9.57	0.98	Point meas'm'ts in Vert. planes.	Fort Independence Section C-D.
Nov. 12.	P.M. 1.23	P.M. 1.50		9.82	0.25	9.00	0.92	Point meas'm'ts in Vert. plane.	Bird Island to Governors Island Section J-K.

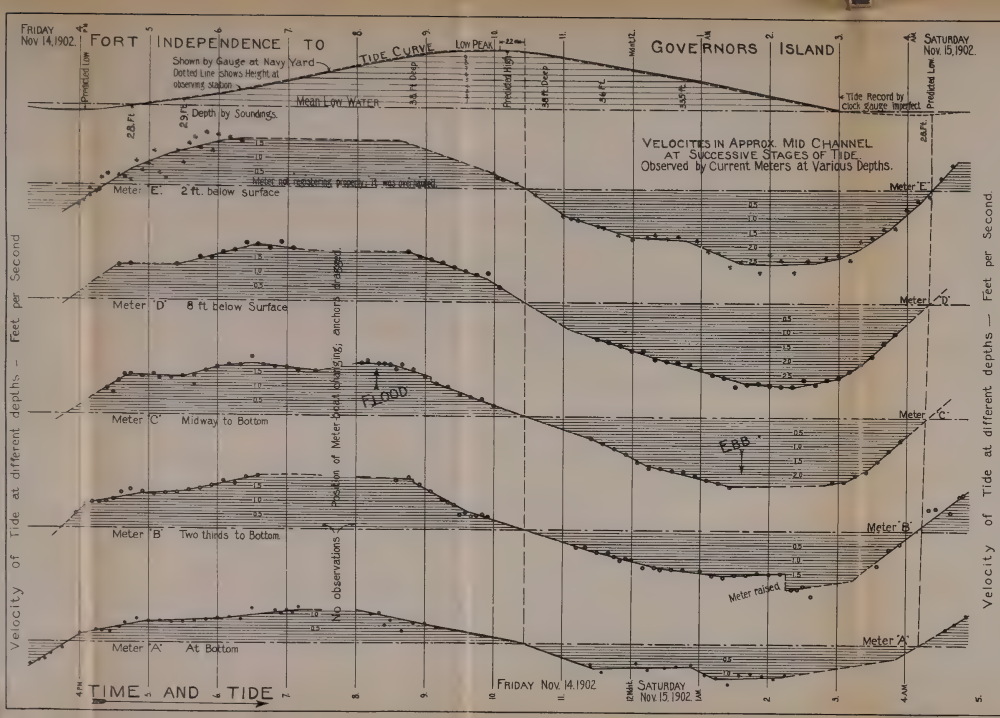
Table showing Time, Character and Location of the Current Meter Measurements of the Tidal Currents in
Boston Harbor and Charles River
and the Relation of Tide when these measurements were made to the Mean Tide.

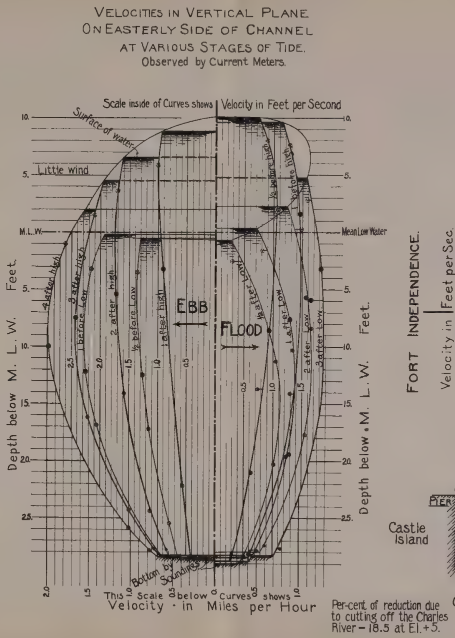
Date 1902	Time of Velocity Measurem't From	Time of Velocity Measurem't To	Stage of Tide	Total Range of this Tide at Navy Yard above M.L.W. From El.	To El.	Feet	Ratio of this Range to Mean Range of 9.8 ft.	Kind of Velocity Measurement Single Meter or Five Meters at Single Points at varying depths	Locality of Section of Velocity Measurement
									Boston Harbor
Nov. 12.	P.M. 3.20	P.M. 4.31		9.25	0.25	9.00	0.92	Point meas'm't in Vertical plane in mid channel.	Fort Independence Section C-D.
Nov. 14. 15.	P.M. 3.17	A.M. 5.00		10.1	-1.15 (-0.5)	Flood 11.25 Ebb 10.6	1.15 1.08	Point meas'm'ts With five meters in Vert. plane in mid channel.	Fort Independence Section C-D.
Nov. 15.	A.M. 11.30	P.M. 10.00		Prd'td 11.0 10.62	-1.45	Ebb 12.45 Flood 12.07	1.27 1.23	Point meas'm'ts with five meters in Vert. plane in mid channel.	Deer Island light Section E-F.
Nov. 17. 18.	P.M. 12.30	A.M. 3.10		12.20 10.80	-1.45	Ebb 13.65 Flood 12.25	1.39 1.25	Point meas'm'ts with five meters in Vert. plane in mid channel.	Ferry Section A.B. Just below "Sect.10."
Nov. 18.	P.M. 1.55	P.M. 4.20		11.95	-1.55	13.50	1.38	Point meas'm'ts in Two Vert. planes	Moon Island Section G.H.
Nov. 18. 19.	P.M. 4.20	A.M. 5.00		11.95 10.92	-1.55	Ebb 13.50 Flood 12.47	1.38 1.27	Point meas'm'ts with four meters in Vert. plane in mid channel.	Moon Island Section G.H.
Dec. 11.	P.M. 2.00	P.M. 3.40		Pred'td 9.0	-0.03	9.0	0.92	Point meas'm'ts in Five Vert. planes in cross section of channel.	Shirley Gut on line of the Metropolitan Sewer.

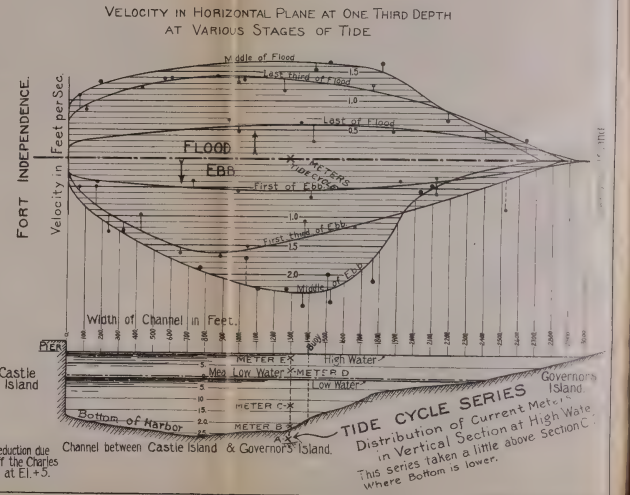

VELOCITY OF TIDAL CURRENTS IN BOSTON HARBOR
SECTION A-B
BELOW SECTION 10. - BETWEEN FERRIES
MONDAY Nov. 17, 1902
TUESDAY Nov. 18, 1902
TIDE CURVE
Shown by Gauge at Navy Yard
Height of water at Station
Rise of Tide Ft.
MEAN LOW WATER
Depth by Soundings
LOW PEAK
Predicted Low
Predicted High
VELOCITIES IN APPROX. MID CHANNEL
AT SUCCESSIVE STAGES OF TIDE
Observed by Current Meters at Various Depths
Wooden Floats
Meter E 3 ft. below surface
Meter D 12 ft. below Surface
Meter C Midway to Bottom
Meter B Two thirds to Bottom
Meter A Near Bottom
Meter raised
Position of Meter changed
FLOOD
EBB
Position of Meter-boat changed to avoid schooner, swinging with tide
No observations
Velocity of Tide at different depths - Feet per Second
TIME AND TIDE
MONDAY Nov. 17, 1902 12 MIDNIGHT TUESDAY Nov. 18, 1902
VELOCITIES IN VERTICAL PLANE
IN APPROX. MID CHANNEL
AT VARIOUS STAGES OF TIDE.
Observed by Current Meters.
Scale inside of Curves shows Velocity in Feet per Second
Surface of Water
Wind
M.L.W.
Mean Low Water
Depth below M. L. W. Feet
Bottom by Soundings
This Scale below Curves shows
Velocity in Miles per Hour
Per-cent of reduction due to cutting off the Charles River -34.5 at El +5.
VELOCITY IN HORIZONTAL PLANE AT ONE THIRD DEPTH
AT VARIOUS STAGES OF TIDE
Middle of Flood
Last Third of Flood
Last of Flood
FLOOD
EBB
METERS TIDE CYCLE
Last of Ebb
First of Ebb
Third of Ebb
Middle of Ebb
Pier Line
BOSTON
Velocity in Feet per Sec.
EAST BOSTON
UNION WHARF BOSTON
Width of Channel in Feet
High water
Mean Low Water
Low water
METER E
METER D
METER C
METER B
METER A
Piles
Bottom of Harbor
Section A-B
Channel at SECTION 10.
Position of Meter boat during continuous observations was slightly down-stream from this Section
TIDE CYCLE SERIES
Distribution of Current Meters in Vertical Section at High Water

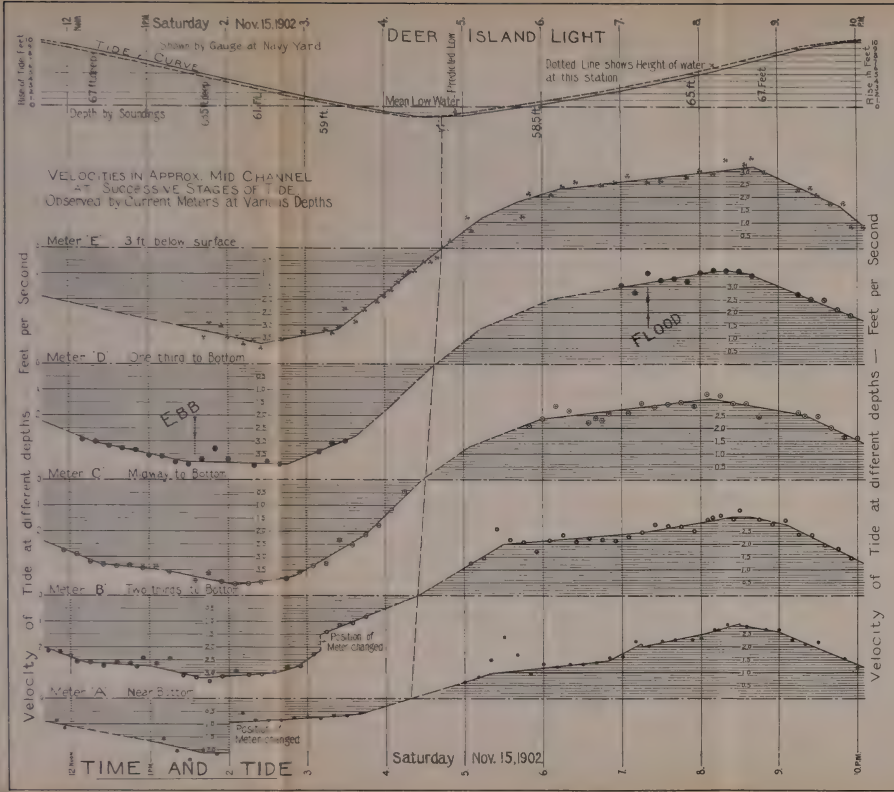
VELOCITY OF TIDAL CURRENTS IN BOSTON HARBOR

SECTION C-D





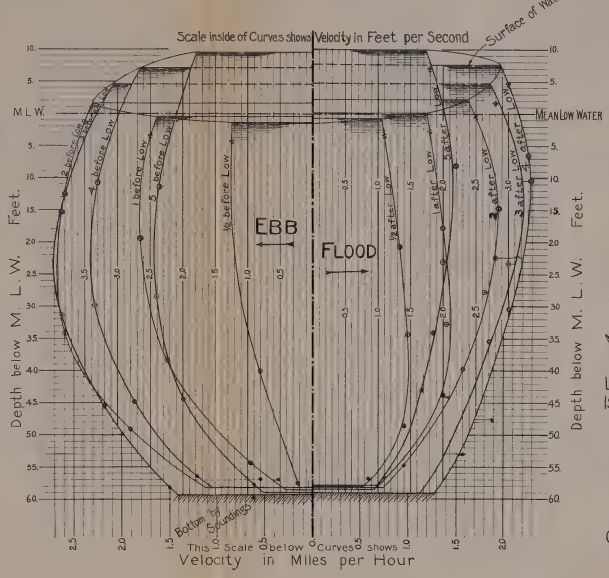




Velocity of Tidal Currents in Boston Harbor

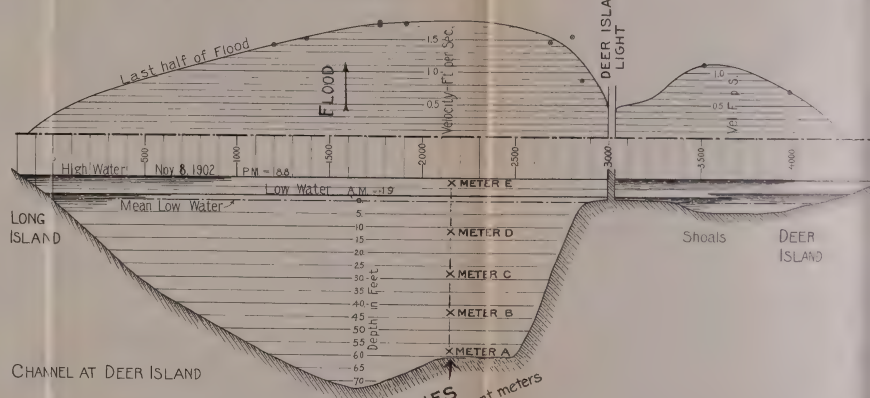
Section E-F

Velocities in Vertical Plane
in Approx. Mid Channel
at Various Stages of Tide.
Observed by Current Meters.

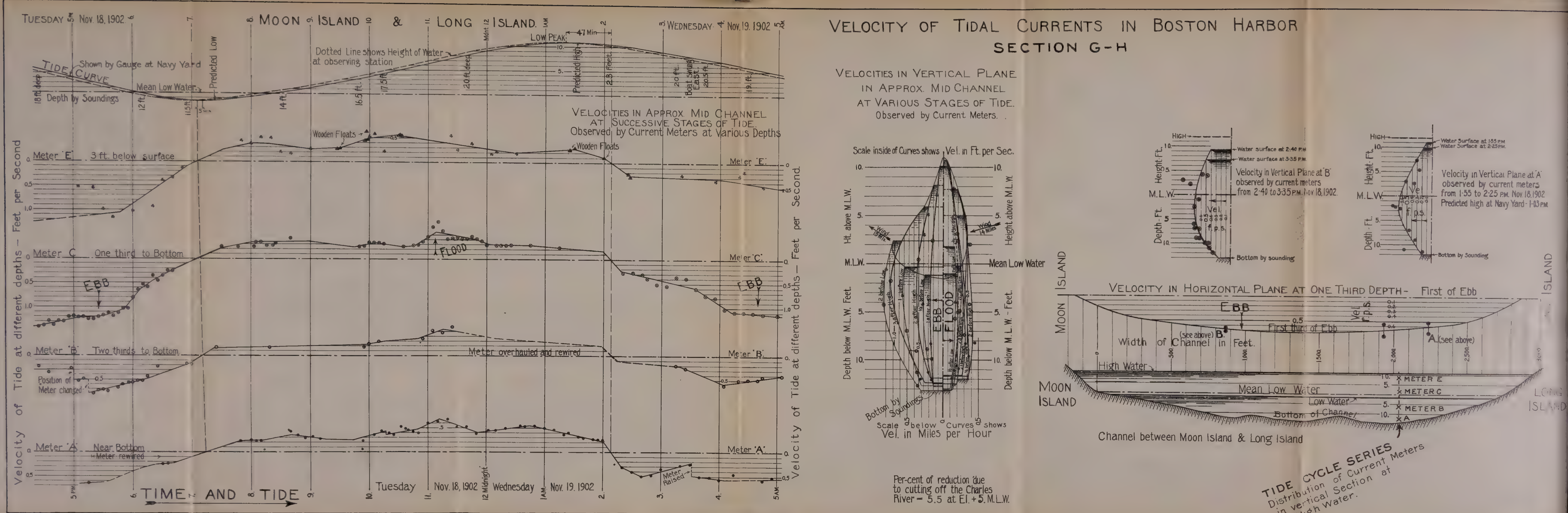


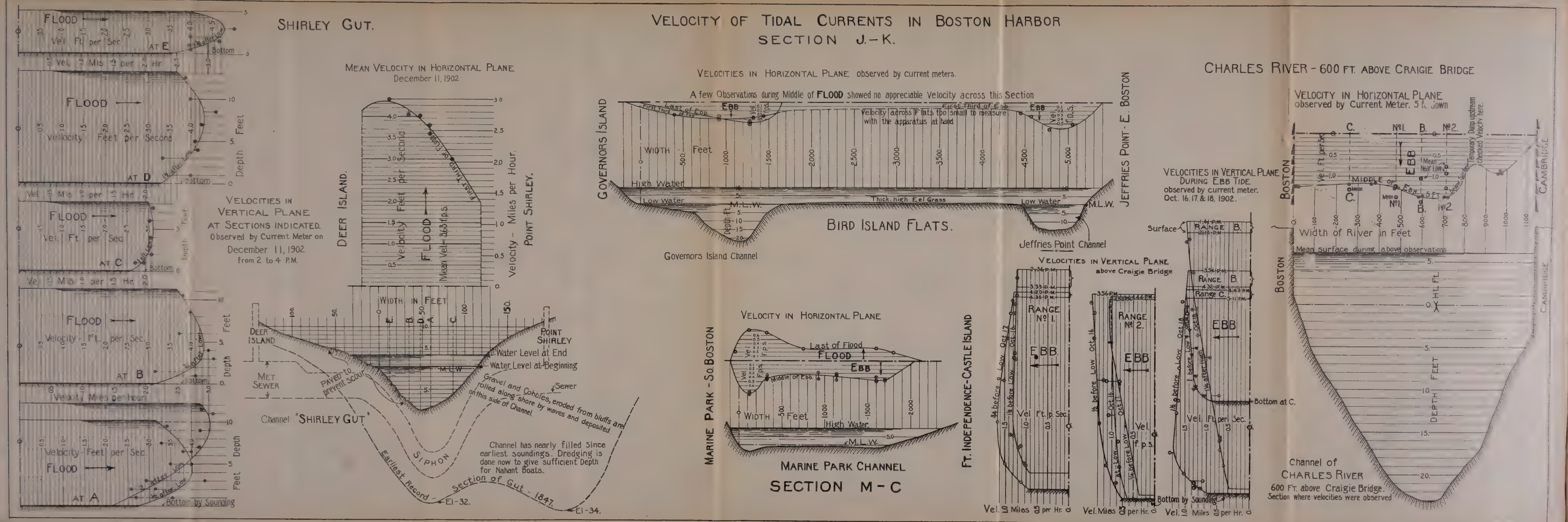
Per-cent of reduction due to cutting off the Charles River — 5.5 at El. + 5 M.L.W.

Velocity in Horizontal Plane at one third depth observed by Current meter on Nov 8 1902 in P.M.



Tide Cycle Series
Distribution of Current meters in vertical Section at High Water.


VELOCITY OF TIDAL CURRENTS IN BOSTON HARBOR
SECTION G-H
MOON ISLAND & LONG ISLAND
TUESDAY Nov. 18, 1902
WEDNESDAY Nov. 19, 1902
TIDE CURVE
Shown by Gauge at Navy Yard
Dotted Line shows Height of Water at observing station
Mean Low Water
Depth by Soundings
Predicted Low
Low Peak
47 Min
Predicted High
VELOCITIES IN APPROX. MID CHANNEL AT SUCCESSIVE STAGES OF TIDE. Observed by Current Meters at Various Depths
Wooden Floats
Meter 'E' 3 ft. below surface
Meter C One third to Bottom
Meter 'B' Two thirds to Bottom
Meter 'A' Near Bottom
Meter rewired
Position of Meter changed
Meter overhauled and rewired
Meter Raised
EBB
FLOOD
Velocity of Tide at different depths - Feet per Second
TIME AND TIDE
Tuesday Nov. 18, 1902 12 Midnight Wednesday Nov. 19, 1902
VELOCITIES IN VERTICAL PLANE IN APPROX. MID CHANNEL AT VARIOUS STAGES OF TIDE. Observed by Current Meters.
Scale inside of Curves shows Vel. in Ft. per Sec.
Ht. above M.L.W.
Height above M.L.W.
Depth below M.L.W. Feet.
Depth below M.L.W. - Feet.
Mean Low Water
Wind 14 Miles
Bottom by Soundings
Scale below Curves shows Vel. in Miles per Hour
Per-cent of reduction due to cutting off the Charles River - 5.5 at El. +5. M.L.W.
Velocity in Vertical Plane at 'B' observed by current meters from 2:40 to 3:35 P.M. Nov 18, 1902.
Water surface at 2:40 P.M.
Water surface at 3:35 P.M.
Bottom by sounding
Velocity in Vertical Plane at 'A' observed by current meters from 1:55 to 2:25 P.M. Nov 18, 1902. Predicted high at Navy Yard - 1:13 P.M.
Water Surface at 1:55 P.M.
Water Surface at 2:25 P.M.
Bottom by Sounding
VELOCITY IN HORIZONTAL PLANE AT ONE THIRD DEPTH - First of Ebb
MOON ISLAND
LONG ISLAND
First third of Ebb
Width of Channel in Feet.
(see above) B.
A. (see above)
High Water
Mean Low Water
Low Water
Bottom of Channel
METER E
METER C
METER B
A
Channel between Moon Island & Long Island
TIDE CYCLE SERIES
Distribution of Current Meters in vertical Section at High Water.



VELOCITY OF TIDAL CURRENTS IN BOSTON HARBOR
SECTION J.-K.
SHIRLEY GUT.
FLOOD
Vel. Ft. per Sec.
AT E
Bottom
Vel. Mls. per Hr.
Velocity Feet per Second
AT D
Depth Feet
AT C
AT B
Velocity Miles per hour
AT A
Bottom by Sounding
VELOCITIES IN VERTICAL PLANE AT SECTIONS INDICATED.
Observed by Current Meter on December 11, 1902 from 2 to 4 P.M.
MEAN VELOCITY IN HORIZONTAL PLANE
December 11, 1902
DEER ISLAND.
POINT SHIRLEY.
Velocity Feet per Second
Velocity - Miles per Hour.
First Third of Flood
Mean Vel. = 3.65 f.p.s.
WIDTH IN FEET
Water Level at End
Water Level at Beginning
M.L.W.
MET. SEWER
PAVED to prevent scour
Gravel and Cobbles, eroded from bluffs are rolled along shore by waves and deposited on this side of Channel.
Sewer
Channel "SHIRLEY GUT"
SIPHON
Channel has nearly filled since earliest soundings. Dredging is done now to give sufficient Depth for Nahant Boats.
Earliest Record - Section of Gut - 1847.
El.-32.
El.-34.
VELOCITIES IN HORIZONTAL PLANE observed by current meters.
A few Observations during Middle of FLOOD showed no appreciable Velocity across this Section
GOVERNORS ISLAND
JEFFRIES POINT - E. BOSTON
Last of Ebb
First Third of Ebb
EBB
Velocity across Flats too small to measure with the apparatus at hand
WIDTH Feet
High Water
Low Water
M.L.W.
Thick, high Eel Grass
BIRD ISLAND FLATS.
Governors Island Channel
Jeffries Point Channel
VELOCITY IN HORIZONTAL PLANE
MARINE PARK - SO. BOSTON
FT. INDEPENDENCE - CASTLE ISLAND
Last of Flood
FLOOD
EBB
Middle of Ebb.
WIDTH Feet
High Water
M.L.W.
MARINE PARK CHANNEL
SECTION M-C
CHARLES RIVER - 600 FT. ABOVE CRAIGIE BRIDGE
VELOCITY IN HORIZONTAL PLANE
observed by Current Meter. 5 ft. down
BOSTON
CAMBRIDGE
EBB
MIDDLE OF EBB
Width of River in Feet
Mean surface during above observations
VELOCITIES IN VERTICAL PLANE DURING EBB TIDE.
observed by current meter. Oct. 16, 17 & 18, 1902.
VELOCITIES IN VERTICAL PLANE above Craigie Bridge
RANGE Nº 1.
RANGE Nº 2.
RANGE B.
RANGE C.
EBB
Surface
Bottom at C.
Bottom by Sounding
Vel. Miles per Hr.
Vel. Ft. per Sec.
DEPTH FEET
Channel of CHARLES RIVER
600 Ft. above Craigie Bridge.
Section where velocities were observed

We have taken pains to obtain from the United States coast survey records the tidal range on those days during which measurements of relative velocity at different depths, given in Report No. 4 of the United States Board, 1861, were measured, in order to reduce them to the conditions existing with tides of mean height. These old determinations are reproduced in comparison with the curves of velocity found by us in 1902 at different depths in nearly the same location, in diagrams a few pages farther on.

Results of Current Observations.

The principal results are set forth graphically in the five sheets of curves facing this page. These cover substantially all of the observations made while five meters were working at once, and they also cover all of our observations on horizontal distribution of velocity.

I have not reproduced the curves from our first series of observations on the distribution of velocity in vertical planes taken by observing one point at a time. These were completely worked up, but, inasmuch as the method of observing at one point at a time was less satisfactory, and since the curves did not differ very materially from those taken five points at a time, it has not been thought worth while to encumber the record with them.

"*The Flood Tide comes in first on the Bottom.*"—This is an old saying among pilots, but we had not given it much attention until our velocity measurements brought it to view; and it will be noted that this view, that the tidal current near to the bottom is decidedly stronger on the flood than it is on the ebb, is diametrically opposed to the views presented by the hydrographer of the United States Board of 1860–65 for in those reports great stress was laid upon the predominant force of the ebb tide and the potency of this predominance as an agent for maintaining depth in channel by scour.*

It will be noted that in the observations between the ferries the tide turned from ebb to flood close to the bottom ten minutes earlier than it did near the top. At the Fort Independence section the flood began twenty minutes earlier on the bottom; and the same phenomenon was observed at Deer Island, it being also twenty minutes earlier here. Some of the point-by-point series of velocity measurements indicated a greater predominance of the early flood than is shown in these observations.

Differences in Temperature and Salinity at Different Depths.

It appears reasonable that there should be some tendency of the warmer and less salt, and therefore lighter, water of the ebb to stay at the top, while the colder and more salt water from the ocean should push in beneath it, and that there should thereby become established a somewhat greater circulation of the fouled surface water seaward than would be the case if there were no such differences of density at play; but our observations would indicate that the amount of motion or increased circulation thereby introduced is not large enough to have any material bearing on the problem of harbor scour and silting up, except to lessen the outward scour. *This doubtless has an important effect in quickening the removal of fouled water and replacing it by new water from the bay*; but, as already stated, we had not time to pursue this study in detail.

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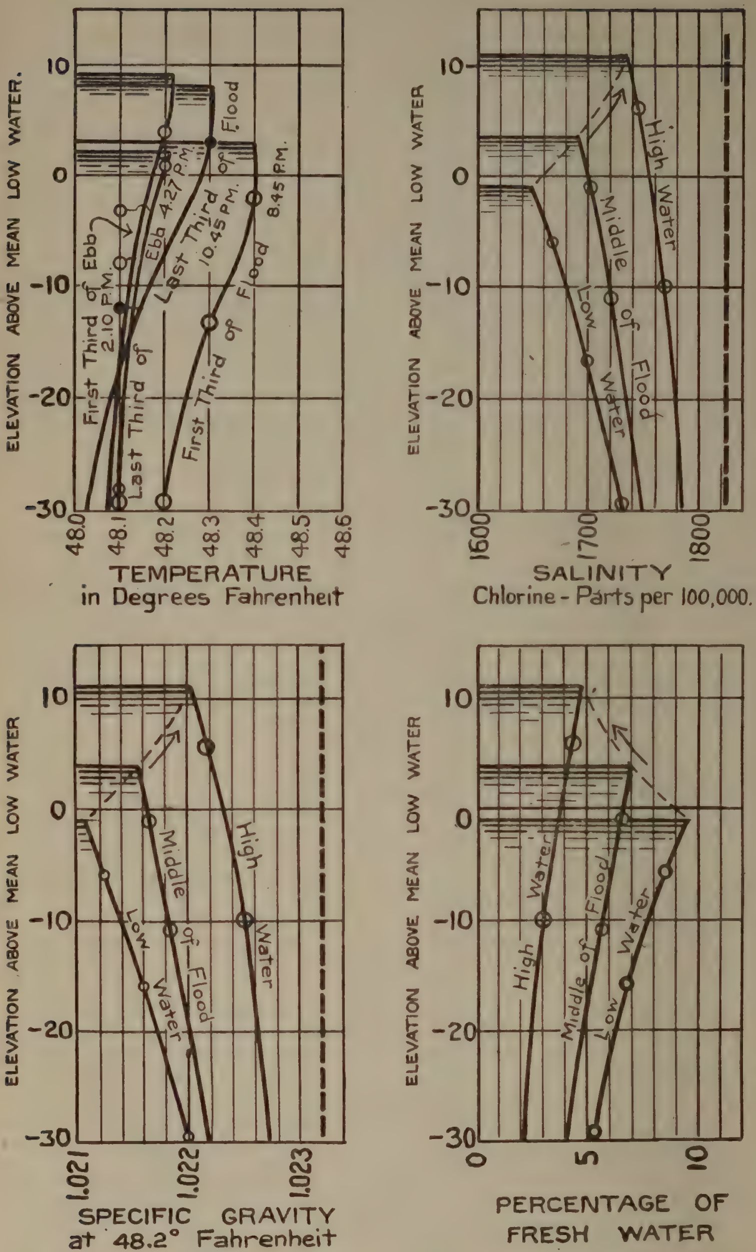
* Many portions of these old reports are characterized by lack of clear, logical analysis, and present a profundity of verbiage over a poverty of precise observation.



BOSTON HARBOR – FERRY SECTION
TEMPERATURE SALINITY AND SPECIFIC GRAVITY OF WATER
IN VERTICAL SECTION DURING CURRENT MEASUREMENTS
TIDE CYCLE SERIES, NOVEMBER 17, 1902.

Opposite Velocities at Turn of Tide.

I found that the flood tide begins to come in on the bottom while the ebb is still slowly running out at the top, and also found that the early flood tide sets in with greater strength near the bottom, so that, as will be seen by inspecting the curves on the following sheets, the curve of distribution of velocity in vertical plane, while apparently held back near the top, bulges out strongly below mid-depth on the early flood; and, on the other hand, during the ebb is relatively stronger near the top and weaker near the bottom. This interesting phenomenon would have been given further study and confirmation had the time of year and pressure of other matters allowed; but the observations at each of the three main harbor sections are concurrent on this point, as also are sundry other curves of vertical distribution of velocity obtained in our earlier measurements and not reproduced here.

There is reason for the predominance of the early flood near to the bottom and for the greater strength of the early ebb near the surface found in the marked excess of the specific gravity of the relatively salt, cool incoming water from the ocean, as compared with the ebb of water warmed by the sun over the shallows at the margins of the estuaries, and further lightened by the admixture with upland water and ground water.

In between our other work we found time to take a few thermophone observations and to collect a few sample bottles of the water from various depths. In collecting these, the stopper was not pulled until the bottle was at the specified depth. After hauling it to the surface as quickly as possible, a fine standardized thermometer, having a scale so open that differences of one-fiftieth of a degree C. were easily read, was introduced, and the temperature noted. The results deduced from these observations at the station between the East Boston ferries are given in the diagram opposite. The constant attention required in keeping the meters clean and working well prevented our taking so many of these samples as we had intended.

It will be noted that there is a plainly marked difference in the temperature and in the degree of salinity at different depths. From these the difference in specific gravity is computed, also the per cent. of fresh water.

Relative Flow of Upland Water. — The flow of the Charles River and the other streams at the time of these current observations was about normal, or not far from the mean of the six warm months. The flow of the Charles at Watertown dam during the period of our current measurement averaged 109 cubic feet per second; and, judging from the water-shed of the other tributary streams, these would not add more than 25 per cent. to the flow of the Charles. Inasmuch as the mean rate of flow of the ebb tide between Boston and East Boston averages 70,000 cubic feet per second, it will be seen that *the volume of upland water is only one-sixth of one per cent.* of the tidal volume, and is therefore utterly insignificant in increasing the volume of the ebb, even though we make the hypothesis that the upland water is wholly held back during the flood and all released on the ebb.

Apparent Predominance of Ebb.

An inspection of the time and tide diagram of currents at section 10 between the ferries indicates a marked predominance of the ebb; but a study of the harbor chart in relation to the distribution of velocity in horizontal plane indicates that this apparent difference was probably

largely due to the fact that during the ebb the momentum of the current sweeping around from the Charles, which is much more powerful than that from Chelsea Creek and the Mystic River, throws the main volume toward the East Boston side; whereas during the flood the velocity is greater nearer to the Boston side. A fuller series of observations would have been needed to trace out the reasons in detail and to balance these curves.*

At Fort Independence section it will be noted that our boat station again happened to be nearer to the line of maximum current on the ebb; but the meter readings do not indicate, either at flood or ebb, a velocity near the bottom large enough to produce scour in ordinary material; and, while in general our tide cycle curves show a greater area on the ebb, I believe this can be best explained by a shifting of the region of greatest velocity and by a change in direction of current like that shown in the cut on p. 397. The difference in the height of succeeding tides also changes this relation, for it will be noted that the two daily tides are of unequal height.

Velocity close to Bottom.

In drawing the curves of velocity close to the bottom on the four folding diagrams I have been guided only by the present series of observations in projecting the curve below the position of the lowest meter. From many velocity measurements that I have made elsewhere by means of instruments which measure closer to the conduit wall, I am sure that the curves might properly have been made more nearly horizontal close to the bottom, thus indicating still smaller bottom velocities than are shown in the diagrams. The curves as I have drawn them thus throw more than the margin of possible lack of precision of measurement against the view that the present currents are too feeble to produce scour.

Comparisons with Subsurface Velocities found by United States Board of 1861.

These are given graphically in the two following diagrams.

Correction has been made in these diagrams for difference in height of tide on the respective dates.

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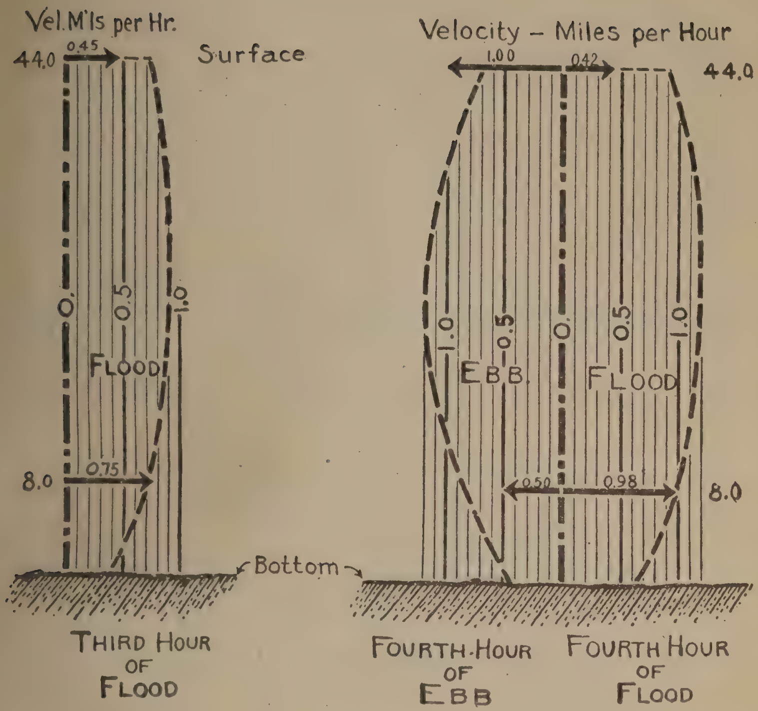
* I should have made further observations for the purpose of clearly establishing these differences, had not the season been so far advanced, with freezing weather expected daily, and so much other work pressing; but these were questions mainly of scientific interest, and a precise answer was not essential to our main problem.

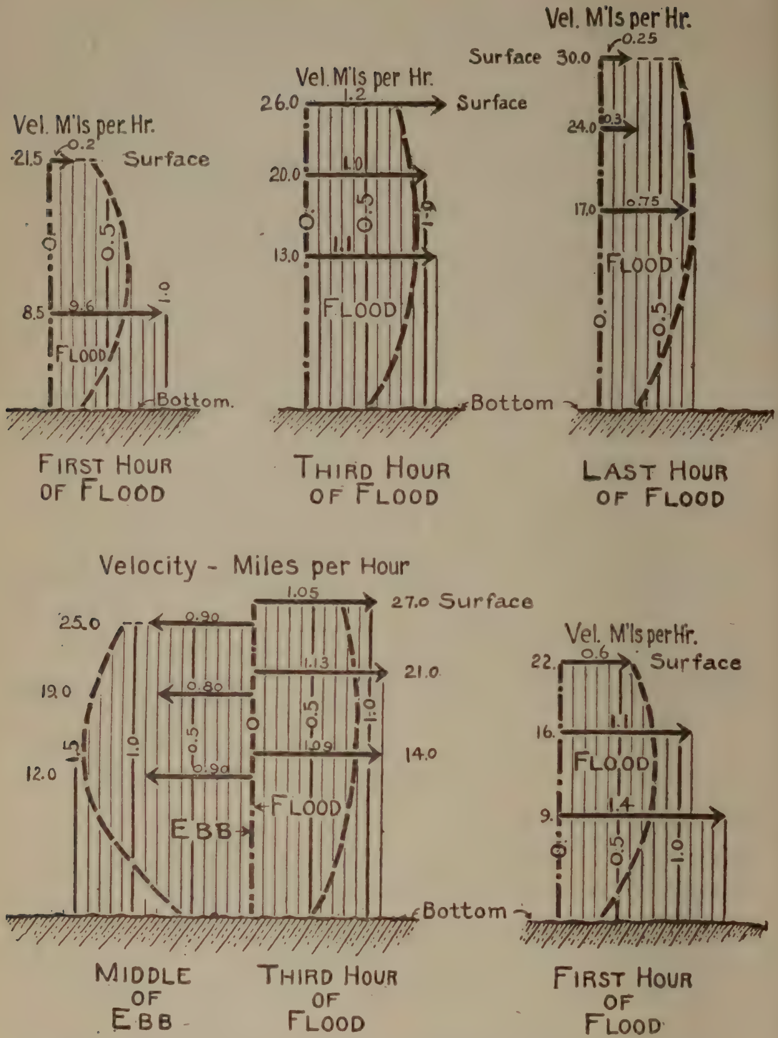


Arrows show comparative velocity of current at different depths at Sta. 47 off East Boston, as found by H. Mitchell, July 1860.

Curves show velocity at approximately the same location and at same stages of tide found by current meter measurements Nov. 1902.

All curves reduced to allow for variation in height of tide.

Comparison of Recent Velocity Measurements with Those of Forty-two Years ago.



Arrows show comparative velocity of current at different depths at Sta. 38 on "Upper Middle," as found by H. Mitchell, Oct. 1860.

Curves show velocity at approximately the same location and at same stages of tide found by current meter measurements, Nov. 1902.

All curves reduced to allow for variation in height of tide.

Comparison of Recent Velocity Measurements with Those of Forty-two Years ago.

VOLUME OF THE CHARLES BASIN AT DIFFERENT DEPTHS.

This was computed from planimeter measurement on the full scale original maps of the Charles River basin, resulting from the new surveys of 1902, and reproduced on about half the original scale elsewhere in this report.

It will be noted by reference to these maps that the soundings were made at very frequent intervals, that the datum used is Boston city base, and that tide gauges were set and observed at some convenient pile or pier near to the scene of work, as the survey advanced from point to point.

These tide gauges were all set by lines of spirit levelling run from standard bench-marks of the city of Boston or those of the Metropolitan Sewer Commission. The contours were sketched at one-foot intervals, and the area within each contour was planimetered.

The volume of the Charles basin itself up stream from Craigie bridge is now determined with an accuracy never before obtained. It is of interest to note that its total contents down to Craigie bridge, included between level planes at the heights of mean low water and mean high water, is 325,200,000 cubic feet.

	Cubic Feet.
Blake, p. 210, gives for the contents between mean low water and mean high water, ...	323,000,000
The new survey gives for the contents between mean low water and grade 8,	260,640,000
Porter's diagram, p. 406, gives for the contents between mean low water and grade 8, ...	220,000,000
Shedd, p. 368, gives for the contents between grade 2 and grade 8, . . .	182,670,600
Porter's diagram gives for the contents between grade 2 and grade 8, . .	190,000,000
The new survey gives for the contents between grade 2 and grade 8, . .	197,720,000
And for the contents between the bottom and grade 8, ...	458,000,000
Shedd, p. 366, gives for the contents between the bottom and grade 8, . .	382,000,000
Porter's diagram gives for the contents between the bottom and grade 8, .	360,000,000

It will be noted that the differences are not large enough to very materially affect the conclusions based on previous values.

Capacity of Charles River Basin from Watertown Dam to One Hundred Feet above Up-stream Side of Craigie Bridge. Areas taken by Planimeter from Original Contour Maps, Scale $\frac{1}{2000}$.

ELEVATION FROM MEAN LOW WATER, UNITED STATES COAST AND GEODETIC SURVEY.	Mean Area equals Tidal Prism for 1 Foot.	Total Contents below Plane 10 Feet above Mean Low Water (Tidal Prism) equals Summation of Preceding Column.	ELEVATION FROM 0, BOSTON BASE.*	Area on this Contour.	Mean Area equals Tidal Prism for 1 Foot.	Total Contents below Grade 10, Boston Base (Tidal Prism).
	Square feet.	Cubic feet		Square feet.	Square feet.	Cubic feet.
+ 10, . .			+ 10, . .	36,131,000		
	36,220,000				35,800,000	
+ 9, . .		36,220,000	+ 9, . .	35,469,000		35,800,000
	35,570,000				35,145,000	
+ 8, . .		71,790,000	+ 8, . .	34,822,000		70,945,000
	34,930,000				34,555,000	
+ 7, . .		106,720,000	+ 7, . .	34,288,000		105,500,000

* Boston base is here considered to be at 0.64 below mean low water, because that is the relation officially adopted a few years ago. Our recent investigations indicate that Boston datum is probably still a little farther below sea level at present, and changing perhaps 0.01 foot per year. See Appendix No. 18.

Capacity of Charles River Basin, etc. — Concluded.

Elevation from Mean Low Water, United States Coast and Geodetic Survey.	Mean Area equals Tidal Prism for 1 Foot.	Total Contents below Plane 10 Feet above Mean Low Water (Tidal Prism) equals Summation of Preceding Column.	Elevation from 0, Boston Base.	Area on this Contour.	Mean Area equals Tidal Prism for 1 Foot.	Total Contents below Grade 10, Boston Base (Tidal Prism).
	Square feet.	Cubic feet.		Square feet.	Square feet.	Cubic feet.
	34,350,000				34,013,000	
+ 6, . .		141,070,000	+ 6, . .	33,739,000		139,513,000
	33,830,000				33,434,000	
+ 5, . .		174,900,000	+ 5, . .	33,129,000		172,947,000
	33,220,000				32,760,000	
+ 4, . .		208,120,000	+ 4, . .	32,391,000		205,707,000
	32,480,000				31,953,000	
+ 3, . .		240,600,000	+ 3, . .	31,515,000		237,660,000
	31,660,000				31,006,000	
+ 2, . .		272,260,000	+ 2, . .	30,498,000		268,666,000
	30,630,000				29,926,000	
+ 1, . .		302,890,000	+ 1, . .	29,345,000		298,592,000
	29,540,000				27,879,000	
0, . .		332,430,000	0, . .	26,413,000		326,471,000
	26,860,000				24,975,000	
— 1, . .		359,290,000	— 1, . .	23,538,000		351,446,000
	24,000,000				22,831,000	
— 2, . .		383,290,000	— 2, . .	22,125,000		374,277,000
	22,330,000				21,414,000	
— 3, . .		405,620,000	— 3, . .	20,704,000		395,691,000
	20,910,000				20,021,000	
— 4, . .		426,530,000	— 4, . .	19,338,000		415,712,000
	19,550,000				18,538,000	
— 5, . .		446,080,000	— 5, . .	17,738,000		434,250,000
	18,000,000				16,389,000	
— 6, . .		464,080,000	— 6, . .	15,041,000		450,639,000
	15,500,000				14,116,000	
— 7, . .		479,580,000	— 7, . .	13,191,000		464,755,000
	13,470,000				12,320,000	
— 8, . .		493,050,000	— 8, . .	11,450,000		477,075,000
	11,650,000				10,662,000	
— 9, . .		504,700,000	— 9, . .	9,874,000		487,737,000
	10,070,000				9,044,000	
—10, . .		514,770,000	—10, . .	8,214,000		496,781,000
	8,450,000				7,413,000	
—11, . .		523,220,000	—11, . .	6,613,000		504,194,000
	6,850,000				5,958,000	
—12, . .		530,070,000	—12, . .	5,302,000		510,152,000
	5,500,000				4,765,000	
—13, . .		535,570,000	—13, . .	4,229,000		514,917,000
	4,350,000				3,941,000	
—14, . .		539,920,000	—14, . .	3,653,000		518,858,000
	3,750,000				3,308,000	
—15, . .		543,670,000	—15, . .	2,963,000		522,166,000
	3,050,000				2,543,000	
—16, . .		546,720,000	—16, . .	2,122,000		524,709,000
	2,250,000				1,767,000	
—17, . .		548,970,000	—17, . .	1,412,000		526,476,000
	1,500,000				1,100,000	
—18, . .		550,470,000	—18, . .	789,000		527,576,000
	830,000				633,000	
—19, . .		551,300,000	—19, . .	477,000		528,209,000
	500,000				414,000	
—20, . .		551,800,000	—20, . .	351,000		528,623,000
	300,000				312,000	
—21, . .		552,100,000	—21, . .	273,000		528,935,000

Confirmation of Mean Velocity from Tidal Prism.

A comparison of the mean velocity as found by the current meters with the mean velocity as found from estimating the volume of the tidal prism that passed a given cross-section within a definite time was made for each of the principal cross-sections of the channel at which current meter observations were made. One of these is presented below. At the Deer Island section they agree fairly well, except near the turn of the tide; but at the other sections the agreement was less close than desired, probably because of shifting of direction and centre of current at different stages of tide, and to small undetermined currents in the side channels and over the flats and to lack of precision in estimating the change in mean depth of tidal prism.

The computation of the flow from the tidal prism requires accurate knowledge of the area of surface at various heights of tide, or of the contents of the basins above the section, for each foot in depth. For the Charles estuary the preceding table gives this with accuracy.

For computing the tidal prism in the other estuaries, we were obliged to make use of such surveys and charts as could be found in the United States engineers office; and, since there has never been occasion to survey all of the various arms of Chelsea Creek and Mystic River with great precision, it is possible that there is some small percentage of error in the volume of the tidal prism above the respective cross-sections where the velocities were measured.

The elevation of water surface must also be known at the beginning and end of the interval of time assumed. We had only the Navy Yard recording gauge as a guide for this. Obviously, since the tide proceeds as a wave, rising about 2 feet per hour and requiring say ten minutes to pass from the Navy Yard to Harvard bridge, the surface is nearly always sloping, and at one time perhaps 4 inches higher at the Navy Yard than it is at Harvard bridge, and at another time 4 inches lower. Lack of measurement of these heights simultaneously for typical areas in the various portions of the estuaries detracted from the precision of estimate of flow from the tidal prism.

The fact that the currents were not always normal to the plane of section, particularly at certain stages of tide, and as shown by the indications of the direction meter on p. 397, also causes some divergence between the observed and the computed results.

It is a mathematical certainty that the sum of the volume of a series of flood tides plus the small volume of upland water must equal the sum of the intermediate ebb tides; and therefore any noteworthy apparent predominance of the resultant of ebb current over flood current must be due to some such cause as shifting of distribution of velocity or to a change in direction, like that shown in sketch on p. 397.

Comparison of Mean Velocity measured with that deduced from Tidal Prism.

Period in Tidal Cycle of 12.4± hrs — Hours before or after Low Tide	Time of Day — Nov. 15, 1902	Tidal Prism: Height of Tide — From gauge record at U.S. Navy Yard, above M.L.W. Feet.	Tidal Prism: Mean Area of Tidal Prism above Deer Island. Mil. Sq. ft.	Tidal Prism: Rise or Fall of Tide in Period (Mean over Area) Ft.	Tidal Prism: Volume of Tidal Prism for Period. Mil. Cu. ft.	Deer Island (E-F): Approx. Height of Tide at Deer Island above M.L.W. Ft.	Deer Island (E-F): Mean Area of Cross Section E-F. Sq. Ft.	Deer Island (E-F): Mean Velocity observed by Current Meters in Vertical Plane F.p.S.	Deer Island (E-F): Ratio of Mean Veloc. in Entire Section to that observed	Deer Island (E-F): Approx. Mean Velocity in Entire Section from Obs't'ns F.p.S.	Deer Island (E-F): Volume passing thro' Section E-F. in Period, per Observat'ns Mil. Cu. ft.	Deer Island (E-F): Per cent of Tidal Prism for Period passing thro' E-F %	Shirley Gut: Mean Area of Cross Section at Shirley Gut. Sq. Ft.	Shirley Gut: Approx. Mean Veloc. Deduced by reducing velocity observed Dec. 11 to this range of Tide F.p.S.	Shirley Gut: Volume passing thro' Shirley Gut in Period. Mil. Cu. Feet.	Shirley Gut: Per Cent of Tidal Prism for Period %	Moon Island (G-H): Mean Area of Cross Section G-H. Sq. Ft.	Moon Island (G-H): Mean Velocity observed by Current Meters in Vertical Plane F.p.S.	Moon Island (G-H): Ratio of Mean Veloc. in Entire Section to that observed	Moon Island (G-H): Approx. Mean Velocity in Entire Section from Obs'ns F.p.S.	Moon Island (G-H): Volume passing thro' Section G-H. in period, per Obs'ns Mil. Cu. ft.	Moon Island (G-H): Per Cent of Tidal Prism for Period %	Per Cent. of Tidal Prism for Period not accounted for. %
4 bef. Low	12 M. / 1 P.M.	9.45 / 7.0	657.	2.4	1570.	8.9 / 6.5	173,000.	3.00	.77	2.3	1440.	91.7	2020.	4.8	35.	2.2	48,300.	0.44	.92	0.40	70.	4.5	1.6
3 " "	2 "	4.3	610.	2.7	1650.	3.8	161,000	3.47	.77	2.6	1550.	94.0	1435.	5.1	26.	1.6	40,700.	0.84	.92	0.77	113.	6.8	-2.4
2 " "	3 "	1.5	557.	2.8	1560.	1.0	148,000	3.47	.77	2.6	1420.	91.1	970.	5.2	18.	1.2	32,900.	1.05	.92	0.97	114.	7.3	0.4
1 bef. Low	4 PM / 5 "	-0.65 / -1.30	500.	2.0	1000.	-1.0 / -0.9	138,000	2.18	.77	1.7	835	83.5	650.	4.4	10.	1.0	26,300.	0.73	.92	0.67	64.	6.4	9.1
1 aft. "	6 "	0.5	482	1.8	870	0.9	138,000.	1.89	.77	1.4	720.	82.8	650.	4.2	10.	1.1	26200.	0.31	.92	0.29	27.	3.1	13.0
2 " "	7 "	2.5	523.	2.1	1100.	3.0	146,000	2.42	.77	1.8	980.	89.1	900	4.5	15.	1.3	31700.	0.27	.92	0.25	28.	2.5	7.1
3 aft. Low	8 PM	5.0	568.	2.6	1480.	5.6	157,000.	2.76	.77	2.1	1200.	81.1	1285	5.0	23.	1.6	38,400.	0.40	.92	0.37	57.	3.4	13.9
4 " "	9 "	7.95	622.	2.9	1800.	8.5	171,000.	2.94	.77	2.3	1390.	77.3	1880	5.3	36.	2.0	46,600.	0.52	.92	0.48	80	4.4	16.3
5 " "	10 "	10.18	673.	1.7	1140.	10.2	182,000	1.86	.77	1.4	940.	82.4	2515	4.0	36.	3.2	53,700.	0.34	.92	0.31	60	5.3	9.1

4 hours of EBB - Per-cent of Tidal Prism passing Deer Island = 90.1 Shirley Gut - 1.5 Moon Island - 6.2 Not accounted for - 2.2
5 " " FLOOD - " " " " " " " " = 82.5 " " = 1.8 " " 3.8 " " " = 11.9

VELOCITIES CONTROLLING THE DEPOSIT AND SCOUR IN THE ESSEX COMPANY'S NORTH CANAL, LAWRENCE, MASS.

Uncommonly good conditions for observing the limiting velocity above which no deposit of silt takes place, and also for observing the velocity at which scour begins, are found in the north canal at Lawrence. This canal takes its water from the long and deep mill pond formed by the dam of the Essex Company across the Merrimack River. This river rises in the New Hampshire mountains, and is moderately turbid with fine sand during the spring freshets of almost every year.

The mean velocity in the upper portion of the canal is high, about 5 feet per second, but gradually diminishes toward the lower end of the canal as water is abstracted for the turbines of the factories.

The canal is a mile in length and of trapezoidal section, about 12 to 14 feet deep in the middle and 2 or 3 feet deep at the edges. It is 100 feet wide at the surface at its up-stream end, and 60 feet wide at its down-stream end, tapering uniformly between these points. The depth is nearly the same throughout its length. The draft of water is much smaller by night than by day.

The alignment of the canal bed is excellent, but the side slopes of the bed are roughened by a riprap of cobble stones, averaging perhaps half a cubic foot each, put in many years ago to prevent the scouring and slipping of the banks; for the canal was constructed through a vast deposit of fine and easily eroded sand.

Near the lower end of the canal this riprap is completely covered by deposits of silt, and within the down-stream quarter of a mile in length of the canal silt is deposited from 6 inches to 1 foot in depth, sometimes in a single season.

The canal is frequently emptied over night, or over Sunday, in summer, for the purpose of various repairs and rearrangements in the canal itself or in connection with the water power of some of the many factories along its banks; and during this rapid emptying and refilling forces are brought into play which cut into these silt deposits and gradually scour them out in large part before the close of the summer season, but with the next spring freshet new deposits take their place.

Inasmuch as the line of demarkation between deposit and no deposit is sharply drawn, and as it is not difficult to measure actual velocity by means of a current meter let down from any one of the numerous bridges across the canal, this canal forms a very convenient place to observe with precision the limiting velocities of deposit and scour for material of this kind.

On April 20, 1902, through the courtesy of Hiram F. Mills, chief engineer and general manager of the Essex Company's works, I made a careful inspection of certain typical areas, and collected specimens of the silt. On the following day, Mr. R. A. Hale, C.E., made measurements of the velocity by means of a current meter. The results of these inspections and measurements were, in brief, as follows: —

At Station No. 1, middle of west chord of Everett Railroad bridge: —

Banks and bed completely and smoothly covered with fine sand, as per sample whose mechanical analysis is given in table following. Deposit 8 inches to 12 inches deep. Surface near the bottom marked with little waves of sand $\frac{3}{8}$ inch high, probably rolled up by the more rapid velocity when emptying canal. Side slopes smooth and free of wave marks. Sand so soft and so like quicksand that one's feet sink into it 3 inches while walking across, or, when standing still for a minute or two, the feet gradually sink into it about 8 to 12 inches. This sand plainly is not being scoured, although it is softer than any silt that I have seen

uncovered at low tide on the shores of Boston harbor, except perhaps the silty sludge in immediate proximity to certain sewers.

Maximum surface velocity in centre found to be,	1.3 feet per second.
Mean velocity of centre section,	1.0 foot per second.
Velocity at 3 inches from bottom,	0.8 foot per second.

This shows that a particularly soft bottom was not eroded by a bottom velocity of about 0.8 foot per second, and that the condition was one that favored deposits.

Station No. 2, at up-stream side of Union Street bridge: —

General appearance the same as at Station No. 1, except that surface of sand in deepest portion of canal is covered by sand waves averaging about one inch high, with crests transverse to current, suggesting a rolling along of the sand grains which perhaps has been induced by the higher velocity from drawing off and refilling the canal a few times very recently, rather than by the ordinary flow. I find, on tramping back and forth over the silt, that it is much more firm than at Station No. 1.

Maximum surface velocity,	1.9 feet per second.
Mean velocity of centre section,	1.5 feet per second.
Velocity at 3 inches from bottom in middle,	1.2 feet per second.

With these velocities silt of this quality is deposited 12 inches deep, and apparently is rolled into waves only by the recent drawing off of canal, since no sand waves are found more than half way up on the sloping sides of canal. The indication is that a bottom velocity of 1.2 feet per second favors deposit and not scour.

Station No. 3, from same cross-section, but about three-quarters distance up slope from centre toward north side and 6 or 8 feet up from bottom level, where there were no sand waves: —

Deposit 8 inches deep, velocity at about 3 inches from bottom found to average 0.9 per second. Condition here is plainly one of deposit, and not of scour.

Station No. 4, up-stream side of Pemberton bridge: —

Up stream from this point the bottom and berms of canal are substantially scoured clean, but a short distance down stream from this point on the northerly edge of berm a deposit begins, and, going down stream, quickly spreads out to 5 feet in width opposite to the penstocks of the Pemberton Mills, and below this gradually widens out, until at Union Street it covers the entire bed of the canal from north side over to foot of south slope.

At Pemberton Bridge, where entire bed is scoured clean, there is some irregularity, found in the distribution of velocity, but the general average of a dozen or twenty observations ran about as follows: —

Mean velocity of entire cross-section,	2.5 feet per second.
Velocity 3 inches from bottom at mid-channel,	1.6 feet per second.
At 10 feet from north side,	1.5 feet per second.
In corner next north wall (at deposit),	0.9 foot per second.

The observations at this point show that a velocity of 1.5 feet per second prevents deposit or produces scour or a rolling along that keeps the bottom clean.

In general, these north canal observations show that *the velocity necessary to prevent deposit or necessary to produce scour of grains of fine river silt and sand of sizes shown by following analysis, and forming part of a mass deposited only less than two months before and not compacted by long standing, was not far from 1.3 to 1.5 feet per second, this velocity being measured at a distance of from 3 inches to 6 inches from bottom.*

These observations thoroughly disprove the oft-quoted, century-old, crude, unreliable observations of Dubuat.

The boiling and eddying of a current has much to do with its power to transport material in suspension. While this canal has riprap on its banks, its straightness and uniformity of section should offset any greater disturbance than is commonly found in natural streams, and should make the results of general applicability.

Mechanical Analysis of Average Samples of Sand carefully collected from within One-quarter to One-half Inch of Surface at Above Stations, analyzed at Lawrence Experiment Station, Massachusetts State Board of Health.

Number of Sample.	No. 1.	No. 2.	No. 3.
10 per cent. finer than (diameter in millimeters),	0.12	0.15	0.04
Uniformity coefficient,	1.40	1.70	3.60
Finer than 2.04 millimeters (per cent. by weight),	100.00	100.00	100.00
Finer than 0.93 millimeters (per cent. by weight),	99.60	99.60	100.00
Finer than 0.46 millimeters (per cent. by weight),	98.00	97.80	99.00
Finer than 0.316 millimeters (per cent. by weight),	95.50	93.40	97.80
Finer than 0.182 millimeters (per cent. by weight),	66.10	33.10	89.20
Finer than 0.105 millimeters (per cent. by weight),	4.30	0.90	32.40
Finer than 0.08 millimeters (per cent. by weight),	–	–	19.10
Finer than 0.04 millimeters (per cent. by weight),	–	–	9.60
Finer than 0.01 millimeters (per cent. by weight),	–	–	0.90

Comparison of Harbor Currents measured, with Limiting Currents for Scour or Silting, as observed in Lawrence Canals.

At the narrowest place, between Boston and East Boston, the velocity will be greater than at points within a half mile up stream or down stream.

The bottom velocity found by our measurements at the section between the East Boston ferries, in mid-channel, was as follows: the maximum velocity at mid-ebb was found to be only 1.2 feet per second, and materially less than this at all other times. It is also without doubt materially less in other parts of the cross-section than at mid-channel.

The velocity will never be materially greater than we found it, for our measurement here happened to fall on one of the most extreme tides of the year, — a tide of 13.65 feet range. The velocity will commonly be much smaller. By diagram on p. 402 we see that, with a tide of mean height, the velocity would be 39 per cent. less, or 0.86 foot per second.

So we see that, judged in the light of the Lawrence canal silt observations, the present maximum velocities in this narrowest section are below the border line between scour and deposit from silt-bearing waters; and from a study of the charts it is plain that at all other points in the inner harbor the velocities are now too low to produce scour or to prevent silt deposit, if the waters were silt-bearing (which they are not).

At the section between Fort Independence and Governor's Island, under a tide of 11.25 feet range, the maximum velocity within 8 inches of the bottom was 1.0 foot per second on the ebb and 1.1 feet on the flood. This is at the division line between the upper harbor and the lower harbor, and is at the smallest section anywhere outside the East

Boston ferries, and consequently must have velocities greater than at any point between. Still, it is found here, as at the ferry section, that the present maximum bottom velocity is too small to scour out any such fine sand as that found in the Lawrence canals.

Proceeding farther outward, the proportionate reduction of current from cutting off the tidal prism of the Charles rapidly becomes less, and a study of the chart shows that little is to be feared from shoaling below this section; and in general it appears demonstrated that the existing currents are now too feeble to prevent deposit of any noteworthy amount, if material for shoaling existed in suspension. Therefore, to still further reduce these currents can cause no harm; and if at the end of a long period some shoaling is found, it will be cheap and easy to dredge it out in connection with the work of improving and increasing the artificial channels which appears certain to go on.

Pulsations.

Variations in the velocity of the current were very noticeable as one listened to the click of the electric sounders connected with the meters. The ear is very quick to note differences of this kind. As I listened to them, the suggestion often came that their rise and fall of frequency bore some analogy to the long, slow swelling waves that one finds as he goes out of the harbor toward the open sea. Mr. Spear and the writer made sundry attempts to record these variations in velocity by counting the clicks of the meter while the eye was on the long second hand of a stop watch, and noting the period covered by five or ten revolutions; also by counting revolutions within fixed intervals of five or ten seconds; but our apparatus was not adapted for making observations of the degree of precision desirable or readily attainable by fitting up for this, and the results are hardly sufficient to warrant presentation.

In general, it may be said that both at Deer Island section and at the East Boston ferry section the velocity would often swell and then fall away to an extent of about ten per cent. from the mean during a one-minute run.

This amount of increase in velocity would have a noteworthy effect on power to produce scour; but similar pulsations have been noted by the United States Geological Survey in its river measurements, and perhaps may have existed to some degree in the north canal, where our observations on scour and silt were made. We would have been glad to pursue this interesting subject further, but the results already obtained appeared sufficient for the purpose.

JOHN R. FREEMAN, C.E.

Appendix No. 12.

REPORT

ON THE

PROBABLE COST OF CARRYING OUT THE REQUIREMENTS SUGGESTED BY PROPERTY OWNERS ALONG BROAD CANAL AND LECHMERE CANAL, CAMBRIDGE, AND SOME OTHER MATTERS RELATIVE THERETO.

By F. W. Hodgdon, C.E.

Boston, Nov. 28, 1902.

John R. Freeman, Esq., C.E., *Chief Engineer, Committee on Charles River Dam, Boston, Mass.*

Dear Sir: — At your request I have made an examination of Broad canal and the Lechmere canal in Cambridge, and have made estimates of the cost of dredging the canals and strengthening and rebuilding the walls and other structures, necessary to fulfil the requirements proposed by the property owners in consideration of the withdrawal of their opposition to the proposed dam across the Charles River, as set forth in a communication from their counsel, Hon. Albert E. Pillsbury, substantially as follows: —

Broad Canal. — To be dredged its Entire Width.

(*a*) From Charles River to Third Street drawbridge, to 10.0 feet below mean low water; equivalent to 9.4 feet below Boston city base.
(*b*) From Third Street to Sixth Street drawbridge, to 6.0 feet below mean low water; equivalent to 5.4 feet below Boston city base.
(*c*) From Sixth Street to railroad bridge, to 4.0 feet below mean low water; equivalent to 3.4 feet below Boston city base.
(*d*) From above railroad drawbridge, to 2.0 feet below mean low water; equivalent to 1.4 feet below Boston city base.

Lechmere Canal. — To be dredged its Entire Width.

(*e*) From Charles River to Sawyer's lumber wharf, to 10.0 feet below mean low water; equivalent to 9.4 feet below Boston city base.
(*f*) From Sawyer's lumber wharf to head of canal at Bent Street, to 6.0 feet below mean low water; equivalent to 5.4 feet below Boston city base.
(*g*) Dredging in Charles River: "Dredge a navigable channel from the lock in the proposed dam to the wharves and the canals, of sufficient width for the passage of all craft bound thither."

(*h*) Dredging maintenance: All above channels to be maintained permanently at all times, doing seasonably all dredging that may be required for that purpose.

(*i*) Ice breaking: Permanently keep the lock channels and the canals at all times sufficiently free from ice to permit unobstructed navigation through the lock and channels and throughout to the railroad draw in Broad canal and to head of Lechmere canal.

I have been familiar with this locality for many years; have examined the plans of both canals which you sent me, which plans, dated November, 1902, give present depths of water and the results of an inspection by Sidney Smith, C.E.; and have myself recently visited and carefully inspected both of the canals and the structures in and around them.

Broad Canal.

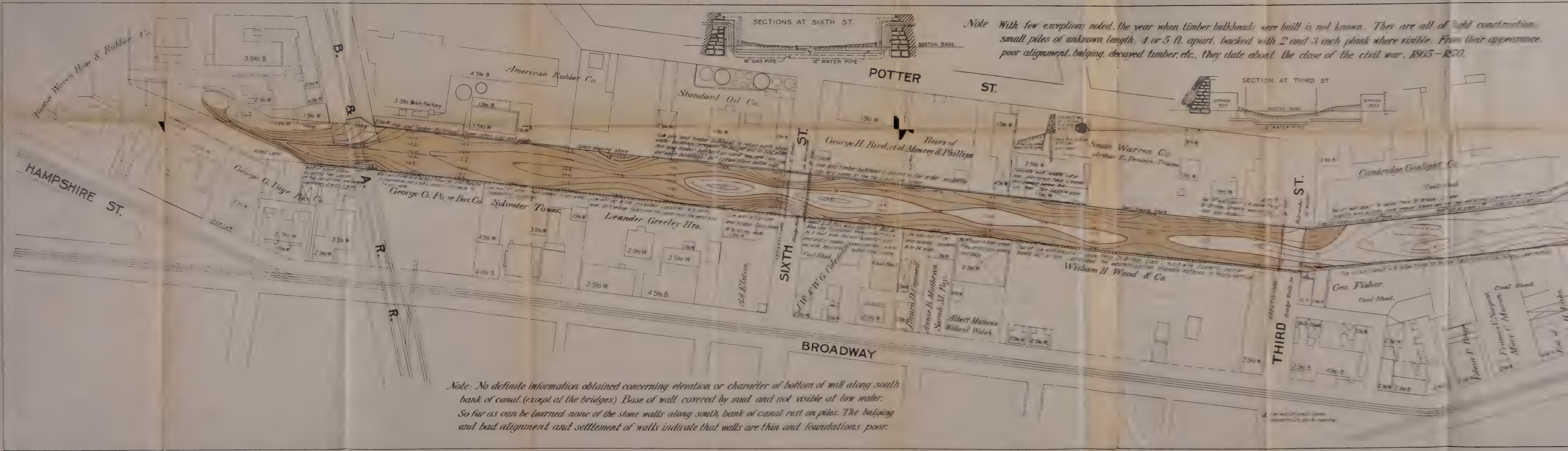
General Description. — The Broad canal is almost solely used by vessels bringing fuel and building materials to certain wharves located along it. From its entrance for a distance of about 1,000 feet it is practically 100 feet wide and 4 to 5 feet deep at mean low water; beyond that it is 80 feet wide, and up to Third Street is 3 to 4 feet deep at mean low water; between Third Street and Sixth Street the bottom is only slightly below mean low water, and between Sixth Street and the railroad bridge it is slightly above mean low water. The depths just stated are to be found only through the centre of the canal, the bottom being considerably higher along both sides. The three highway bridges and one railroad bridge crossing the canal are all provided with draws for the passage of vessels.

At the Third Street and again at the Sixth Street bridge the canal is crossed by two pipe siphons laid below the present bottom of the canal; at each bridge a 16 inch gas main and a 12 inch water main. At the First Street bridge the canal is crossed by a 12 inch water main laid below the present surface. If the canal is dredged to the depth specified by the property owners, all of these pipes will have to be lowered.

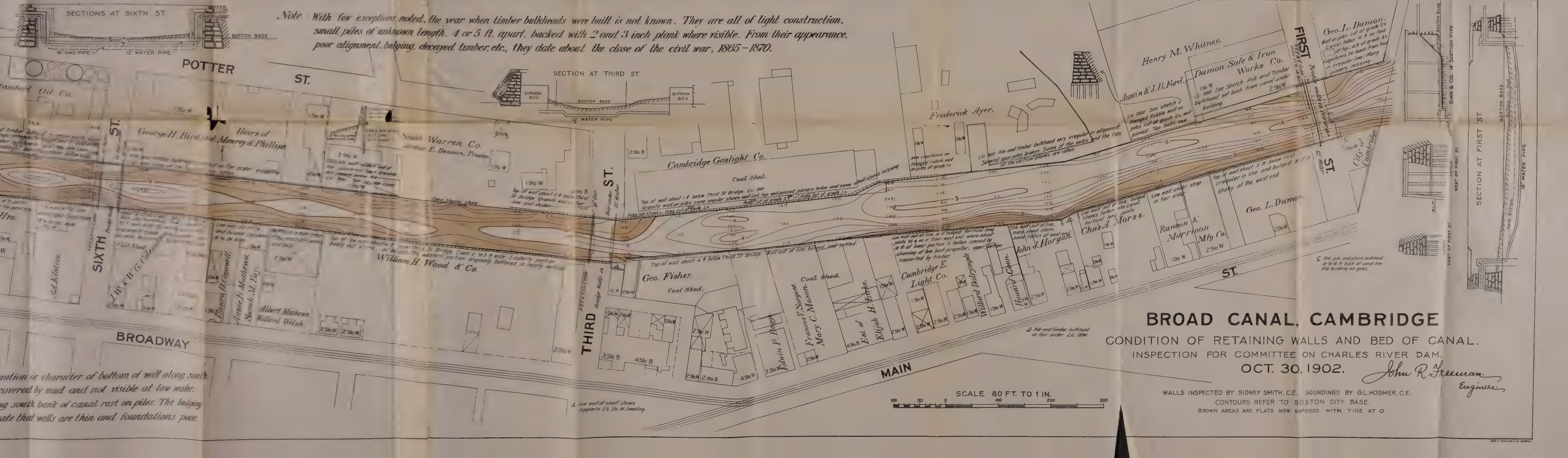
The railroad bridge is practically at the head of navigation, as the portion of the canal lying beyond it is now used as a dump and is being rapidly filled up. There is at the present time scant room to get even a very small vessel above this bridge. Long sections of the bank of the canal on both sides have ceased to be used for shipping, and are now occupied by stables, storehouses or manufacturing buildings; and above Sixth Street only a small portion of the frontage is apparently ever used at the present time as wharves for any class of vessels.

The southerly boundary of the Broad canal for nearly its whole length is a stone sea wall, very much dilapidated; and, from all the information I have been able to obtain, this wall rests generally on a stratum of sand at or about the level of low tide; portions of this south wall appear to have had the top recently rebuilt, and one section just below Sixth Street is said to have been recently rebuilt with its foundation resting on blue clay.

Above Third Street the northerly boundary of the canal consists largely of a timber bulkhead, other portions being stone walls similar to those on the southerly side. Below Third Street, along the front of the property of the Cambridge Gas Light Company, is a stone wall supported on a pile foundation, and another similar wall is situated a short distance above the First Street bridge. Between these last two walls is a timber bulkhead, set back a few feet from the line of the canal. From the entrance of the canal to a short distance above the First Street bridge is a stone sea wall, set back 15 feet from the line of the canal, and resting on piles.



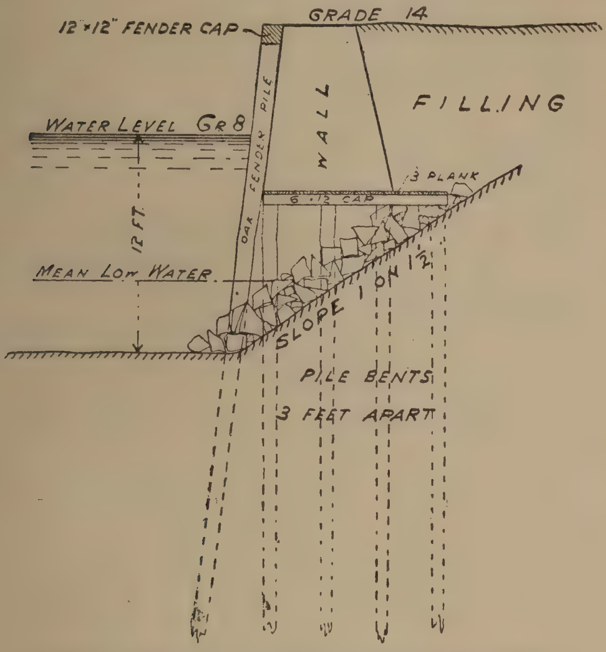
SECTIONS AT SIXTH ST.
16" GAS PIPE
12" WATER PIPE
BOSTON BASE
Note With few exceptions noted, the year when timber bulkheads were built is not known. They are all of light construction, small piles of unknown length, 4 or 5 ft. apart, backed with 2 and 3 inch plank where visible. From their appearance, poor alignment, bulging, decayed timber, etc., they date about the close of the civil war, 1865–1870.
POTTER
ST.
SECTION AT THIRD ST.
Boston Woven Hose & Rubber Co.
American Rubber Co.
3 Sto Brick Factory
Standard Oil Co.
B.
&
A.
R.
R.
HAMPSHIRE ST.
George G. Page Box Co.
George G. Page Box Co.
Sylvester Tower
Leander Greeley Hrs.
Open sloping shore
SIXTH
ST.
George H. Bird, et al.
Heirs of Mowrey & Phillips
Smith Warren Co.
Arthur E. Denison, Trustee
Cambridge Gaslight Co.
A.A. Elston
J.W. & W.G. Coleman
Coal Shed
Annie B. Mathews
Sarah M. Foy
Albert Mathews
Willard Welsh
William H. Wood & Co.
THIRD
ST.
Geo. Fisher
Coal Shed
BROADWAY
Note: No definite information obtained concerning elevation or character of bottom of wall along south bank of canal (except at the bridges). Base of wall covered by mud and not visible at low water. So far as can be learned none of the stone walls along south bank of canal rest on piles. The bulging and bad alignment and settlement of walls indicate that walls are thin and foundations poor.


SECTIONS AT SIXTH ST.
BOSTON BASE
16" GAS PIPE
12" WATER PIPE
Note With few exceptions noted, the year when timber bulkheads were built is not known. They are all of light construction, small piles of unknown length, 4 or 5 ft. apart, backed with 2 and 3 inch plank where visible. From their appearance, poor alignment, bulging, decayed timber, etc., they date about the close of the civil war, 1865-1870.
POTTER
ST.
Standard Oil Co.
SECTION AT THIRD ST.
SIPHON BOX
BOSTON BASE
WATER PIPE
George H. Bird, est.
Heirs of Mowrey & Phillips
Smith Warren Co.
Arthur E. Denison, Trustee.
Frederick Ayer.
Cambridge Gaslight Co.
Coal Shed.
Henry M. Whitney.
Austin & J. B. Ford.
Damon Safe & Iron Works Co.
Geo. L. Damon.
FIRST
ST.
City of Cambridge
Chas. A. Morss.
Rawson & Morrison Mfg Co.
Geo. L. Damon.
John J. Horgan.
Cambridge E. Light Co.
Willard Dalrymple.
Elijah H. Luke.
Est. of
Mary C. Mason.
Frances V. Sargent
Edwin P. Boggs.
Geo. Fisher.
Coal Shed.
William H. Wood & Co.
SIXTH
THIRD
ST.
BROADWAY
MAIN
ST.
Albert Mathews.
Willard Welsh.
Annie F. Matthews.
Sarah M. Fay.
Coal Shed.
SECTION AT FIRST ST.
12" WATER PIPE
BOSTON BASE
GINN & CO. 14" SUCTION PIPE
EAST OF FIRST ST.
WEST OF FIRST ST.
vation or character of bottom of wall along south
covered by mud and not visible at low water.
g south bank of canal rest on piles. The bulging
ate that walls are thin and foundations poor.
BROAD CANAL, CAMBRIDGE
CONDITION OF RETAINING WALLS AND BED OF CANAL.
INSPECTION FOR COMMITTEE ON CHARLES RIVER DAM.
OCT. 30, 1902.
John R. Freeman Engineer.
SCALE 80 FT. TO 1 IN.
100 50 0 100 200 300
WALLS INSPECTED BY SIDNEY SMITH, C.E. SOUNDINGS BY G.L. HOSMER, C.E.
CONTOURS REFER TO BOSTON CITY BASE.
BROWN AREAS ARE FLATS NOW EXPOSED WITH TIDE AT O.

Broad Canal, between Third and Sixth Streets, Nov. 24, 1902. Low Tide + Grade .64, Boston Base.

Necessity for rebuilding Walls to meet the Proposed Requirements. — At the present time it is probably not practicable to dredge the berths alongside the canal to a materially greater depth than they now have, because by so doing the banks which now support the material on which the retaining walls rest would be removed in most cases, and the walls themselves would fall into the canal. In order to dredge to the depth required by the proposition submitted by the property owners, and to allow vessels having a draft corresponding to that depth to lie along-

Scale 1 Inch = about 10 Feet.



TYPE OF CANAL WALL PROPOSED FOR 12 FOOT CHANNEL.
F. W. HODGDON, C.E., DECEMBER, 1902.

side the quay wall, it would be necessary to entirely reconstruct these walls, excepting possibly the wall at the entrance of the canal on its northerly side.

Since, as before stated, portions of the frontage are occupied by buildings in such a manner that there is no reason for vessels to come close to the sides of the canal, in making my estimates I have planned at these places to let the existing walls or bulkheads stand, and not to dredge near enough to undermine them; and, after the remaining width of the canal has been dredged to the required depth, simply to riprap the slope in their front, in order to prevent the supporting earth from being washed out from under the foundations of the walls or bulkheads.

Wherever there is an opportunity for a vessel to lie alongside the wharf, my estimate covers the cost of construction of such a wall as would allow a vessel drawing the full available depth to come alongside.

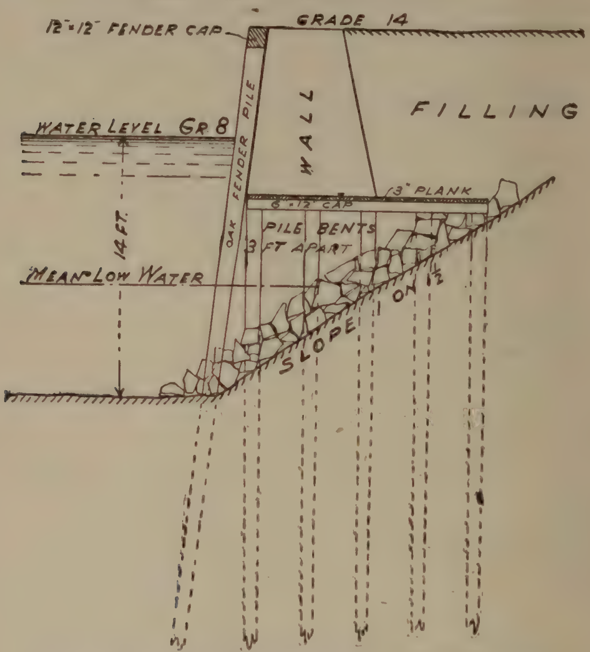
The forms of wall proposed are shown on the accompanying sketches. These are, in my opinion, the cheapest form of construction which will give a permanent and satisfactory face to the reconstructed canal.

In doing this work it will not be necessary to make any extensive reconstruction of the bridges over the canal, but there are some buildings which will have to be removed and replaced.

Preventing Obstruction by Ice. — I am not fully satisfied as to the best method of accomplishing the requirement suggested on behalf of the property owners, — that the public authorities shall "permanently keep the channels and canals at all times sufficiently free from ice to permit unobstructed navigation."

In this region the ordinary method of keeping a harbor channel clear from ice for the purposes of navigation is to run a tow boat back and

Scale 1 Inch = about 10 Feet.



TYPE OF CANAL WALL PROPOSED FOR 14 FOOT CHANNEL.
F. W. HODGDON, C.E., DECEMBER, 1902.

forth through the ice, breaking it up, and gradually working it out so that it will drift into the open harbor. Since the basin will be closed by the proposed dam, it will be practically impossible to follow this method; and it seems to me the only way to fulfil this requirement to the letter will be to keep a tow boat constantly at work in freezing weather, running back and forth through the canal and the channels leading to it, keeping the water in motion, and preventing the formation of ice of any considerable thickness. The employment of a tow boat for this purpose for the four months of winter I have estimated at $4,000 per year, which, at 4 per cent., would call for a capitalization of $100,000.

It is to be noted that under present conditions the Charles basin is not infrequently ice-bound for days at a time, and that, if a vessel must go to sea or must come to a berth, the burden of ice breaking does not rest on the public.

Estimate No. 1. — Broad Canal.

For the excavation of Broad canal to the depths specified by the property owners, and with the walls and bulkheads along its banks reconstructed in accordance with the drawings herewith submitted, except where permanent buildings now exist: —

Dredging in canal and for approaches in main basin, 85,000 cubic yards, at 30 cents,		$25,500
Walls: —		
South side: —		
Rebuilding 1,290 lineal feet sea wall, at $40,	$51,600	
Riprapping 60 lineal feet sea wall, at $3,	180	
Rebuilding 885 lineal feet sea wall, at $37,	32,745	
Rebuilding 560 lineal feet sea wall, at $35,	19,600	
Riprapping 195 lineal feet sea wall, at $2,	390	
Riprapping 100 lineal feet sea wall, at $1,	100	
		104,615
North side: —		
Rebuilding 1,120 lineal feet sea wall, at $40,	$44,800	
Riprapping 340 lineal feet sea wall, at $3,	1,020	
Rebuilding 520 lineal feet sea wall, at $37,	19,240	
Riprapping 160 lineal feet sea wall, at $2.50,	400	
Rebuilding 110 lineal feet sea wall, at $35,	3,850	
Riprapping 500 lineal feet sea wall, at $2,	1,000	
Building 180 lineal feet bulkhead, at $8,	1,440	
		71,750
Lowering pipes under canal and repairs to bridges: —		
At First Street,		1,500
At Third Street,		2,000
At Sixth Street,		2,000
Care of structures interfering with work,		3,000
		$210,365
Incidental expenses and supervision, 10 per cent.,		21,000
Total for Broad canal,		$231,365

The above estimate of 85,000 cubic yards covers a channel 200 feet wide on the bottom, extending from the entrance of the canal to deep water in the Charles basin, and also covers excavating the canal to the full depth for a width which will leave banks at its sides sloping at an angle of $1\frac{1}{2}$ to 1, up to the foot of the walls on either side at about the level of mean low water.

My estimate of $176,365 for cost of the walls on both sides of Broad canal includes the taking down of the present structures and the necessary excavations to prepare the foundations for the new walls, and also the construction of the new walls and the necessary back filling in rear of them. It also includes whatever riprapping is necessary on the slopes in front of those portions of the walls and bulkheads which it is proposed not to rebuild.

A Less Expensive Plan. — After a careful examination of the canal, while for the moment disregarding the gain by constant water level, I have made the following estimate of the cost of reconstructing it in such a manner as will give all of those owners who now use wharves for shipping a depth of water at least equal to that now enjoyed by them. In order to do this it would not be necessary to dredge quite as deep as

is specified in the proposition presented by Mr. Pillsbury on behalf of the owners, but, as the amount to be saved by dredging only to the lesser depth would be small, I have used the same estimate for the dredging as in the estimate first given: —

The proposed basin level is grade 8, city base.

Authorities differ several tenths of a foot in the relation between mean low water and city base; but, assuming mean low water to be 0.64 foot above city base, —

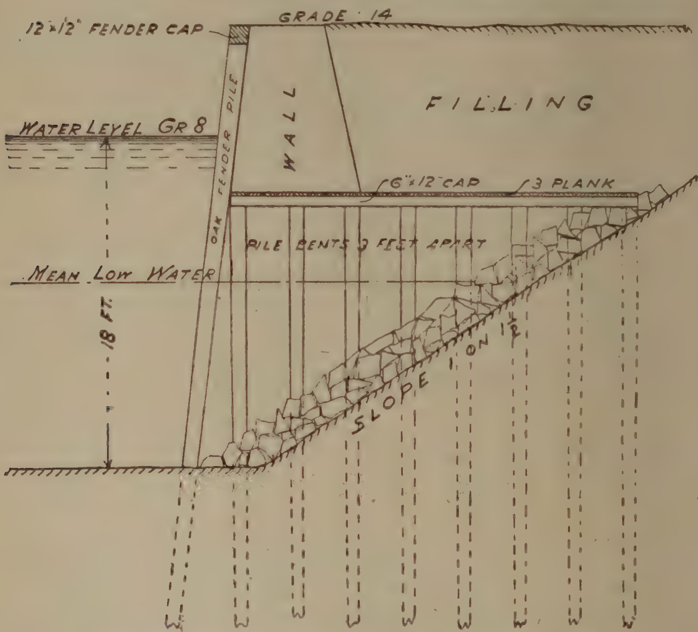
Present high water ordinary neap tides is grade 8.74, city base.

Present high water ordinary spring tides is grade 11.64, city base.

Present mean high water is grade 10.24, city base.

In making changes in the walls of the canal so that the same vessels can be brought alongside them under the proposed new conditions as are now brought there during the time of high water at ordinary spring

Scale 1 Inch = about 10 Feet.



TYPE OF CANAL WALL PROPOSED FOR 18 FOOT CHANNEL.
F. W. HODGDON, C.E., DECEMBER, 1902.

tides, it will be necessary to dredge in front of most of them to the depth of 4 to 5 feet, and, as before stated, this would undoubtedly undermine and destroy them. For this reason it may, in my opinion, be necessary to replace the existing walls with new ones wherever the owners would desire to have such vessels lie alongside in the future. For replacing the walls I have estimated for the same class of work as in the estimate first given, the only practical difference between the two estimates being the total length of this class of work.

If the canal is improved as suggested in the second estimate, the facilities furnished will be vastly better than those existing at present, as, owing to the surface of the water being kept at a constant level, vessels of the maximum draft can be moved to and from the wharves

Broad Canal, between Third and Sixth Streets, July 11, 1902.

Broad Canal, between Third and First Streets, Nov. 24, 1902. Low Tide at 12.10 P.M. Grade + .64, Boston Base.

at all times, instead of only at times of spring tides, as at present; also, the vessels lying at the wharves will be water-borne all the time, instead of lying aground the larger part of the time, as at present, and will thus avoid the tremendous strains caused by such grounding.

It should, in fairness, be noted also that, although it may be planned to have large vessels arrive and be berthed at high water in spring tides, yet coastwise shipping is liable to many delays caused by wind and weather. The total time in each month that the present extreme depths are available is very short.

At the present time, undoubtedly, plans are made to have the larger class of vessels arrive at times of spring tides, so as to take advantage of the greater depth of water existing then; but at times the advantage hoped to be gained is lost by the vessel being delayed, and not arriving until the spring tides have passed. In my opinion, if the canal should be excavated 2 feet deeper than at present, and the water maintained at grade 8, city base, all the time, very few vessels which now come to these wharves would be barred out; and, if the basin were held higher than grade 8, correspondingly less excavation would be required.

In the matter of ice, also, I must call attention to the fact that the owners ask to have the channel kept clear at all times, while now weeks often elapse during the winter when no vessel can get through or into this canal without first hiring a tow boat to go in advance, to break up the ice and clear for it a channel.

Some wharf owners would be benefited if the dam were built and nothing done to the canal, while others would be seriously damaged.

Different owners will be differently affected by the change from tidal conditions to constant level; but it is difficult to reconcile all interests in an attempt to say just what constant level, whether 8 or 9, or some other level, will, without dredging, bring any advantage at times of low tide sufficient to offset the present convenience of bringing a large vessel to dock at the hour of high water, and, on the whole, some dredging appears necessary.

Any estimate which purported to balance the benefit to one owner against the damage done to another would require much more information as to the amount and kind of business done at the different wharves than is at my command; and for this reason I have provided in my estimates for such changes as would enable any owner to carry on his business with vessels of the same class as those now in use, although by so doing all the owners would get much better accommodations than they have at present.

In studying the matter I considered a plan substantially as follows: to dredge through the centre of the canal a channel 4 feet deeper than the present depth and 60 feet wide on the bottom at the outer end, where the canal is 100 feet wide between walls and 40 feet wide on the bottom the remaining length; where the canal is 80 feet between walls, sloping the bottom of the canal for the remaining width from the dredged depth up to the level of the present bottom at the face of the side walls of the canal; as soon as the excavation is completed, these sloping banks to be riprapped wherever necessary to keep the foundation from being washed out from under the walls at the sides of the canal.

If this were done, very many of the vessels now using the canal would be able to come alongside their wharves at any time, just as they are able to do now only at or about the time of high tide, and would be water-borne at all times, thus having much better accommodations than at present.

The larger vessels, however, while they would be able to float up the canal at any and all times to a point opposite the wharves to which

they are bound, would not be able to breast into their berths alongside the wharves until they had been partially discharged. The discharging could be readily done by using longer gang planks and derrick arms than are at present in use there; but while waiting for this to be done they would so obstruct the canal as to prevent vessels of a similar size from passing up or down, although many of the smaller-sized vessels could still pass them.

The cost of carrying out such a plan would not be very great; it would probably not exceed $40,000, including the changes which it would be necessary to make in the appliances at the various wharves.

I rejected this plan, as it seemed to me that in general it would be in the nature of a makeshift rather than a proper solution of the problem. It would also be very difficult, if not impossible, to bring about among the various wharf owners, whose interests naturally conflict, the co-operation necessary to provide that vessels blocking the channel should give way temporarily to enable others to pass; and, moreover, the walls and bulkheads now lining the canal are generally old and in poor condition, and will undoubtedly have to be repaired or replaced in a few years; and this can be done much more cheaply now, in anticipation of the building of the dam, than after the dam is built and the water level maintained at grade 8. This increase in cost would be a considerable tax on the property, and would very likely delay its development.

The cost of preparing the foundations for the necessary structures required on account of the increased depth would be much less if they could be constructed before the dam is built.

Estimate No. 2. (Broad Canal.)

For giving the same depth of water at all times as now exists at high water of spring tides, and rebuilding all walls now used for shipping: —

Dredging 85,000 cubic yards in canal and for channels in main basin, same as in Estimate No. 1, at 30 cents,	$25,500
Walls and bulkheads: —	
From entrance to Third Street: —	
2,100 feet to be removed and rebuilt, at $40,	84,000
800 feet to be riprapped, at $3,	2,400
Third Street to Sixth Street: —	
600 feet to be removed and rebuilt, at $37,	22,200
965 feet to be riprapped, at $2.50,	1,737
210 feet beach,	–
Sixth Street to railroad bridge: —	
410 feet to be removed and rebuilt, at $35,	14,350
955 feet to be riprapped, at $2,	1,910
155 feet beach,	–
Above railroad bridge: —	
100 feet to be riprapped, at $1,	100
180 feet bulkhead to be built, at $8,	1,440
Pipes and repairs at bridges: —	
First Street,	1,500
Third Street,	2,000
Sixth Street,	2,000
Care of structures interfering with work,	3,000
	$152,137
Incidental expenses and supervision, 10 per cent.,	15,200
Total for Broad canal,	$167,337

LECHMERE CANAL
CAMBRIDGE
CONDITION OF RETAINING WALLS AND BED OF CANAL.
INSPECTION FOR
Committee on Charles River Dam.
NOV. 1, 1902
WALLS INSPECTED BY SIDNEY SMITH C.E.
SOUNDINGS BY G.L. HOSMER, C.E.
Contours refer to Boston City Base.
Brown Areas are flats now exposed with tide at a
SCALE 80 FT. TO 1 IN.
SEWER CROSSING, COMMERCIAL AVE.
SYPHON
CAMBRIDGE ST.
BRIDGE ST.
FIRST ST.
CHARLES ST.
BENT ST.
ROGERS ST.
BINNEY ST.
COMMERCIAL AVENUE
THE FRONT
Craigie Bridge
E.D. Sawyer Lumber Co.
Everett W. Brooks
Herbert N. Sanborn
Chas. Linehan
J. Frank Wellington
Benj. G. Smith Tr.
G. Gorham Peters
Heirs of Geo. H. Peters
W. C. Peters
John Harrington
Lee M. Friedman
John T. Scully
Catherine Doherty
Lawrence P. & Parker F. Soule
Proposed Limit of Filling
Granite Wall
24" SEWER SYPHON
OUTLET - BINNEY ST. SEWER
OUTLET - BRIDGE ST. SEWER
SEWER OUTLET
PRIVY
Coal Shed-W
Abt half of bulk-head has been recapped. Half is rotten.
Double row of piles abt 4 ft. apart. Caps 10"x12" backed with 2" to 5" timber. Line fair. Tops of piles, caps and upper timbers rotten. Portions of cap missing.
Pile and timber bulkhead designed by Barbour, C.E. Double row of piles 3 ft. apart. Tops rotten. 2" to 5" timber. Upper timber rotten. Bulkhead in fair line. About one-half of cap missing; old cap remaining is rotten. Recapped.
The bulkhead at head of canal is of pine piles, abt 3.5 ft. long, abt 5 ft. apart, backed by 5" timber. Caps 12"x14". The portion at head is broken, and 12 ft. out of line, pressed into canal by ashes filling.
Dock wall out of line and bulged slightly
Dock wall out of line and bulged. Several long vertical joints. Caps 2 to 3 ft. wide.
Dock wall out of line and bulged
Dock wall of small stone, poorly laid. Corner fallen

Electrical Cables under Canal. — No special estimate has been made as to the cost of taking up and relaying the various cables now crossing the canal, as the necessary work on these would undoubtedly be done by and at the expense of the owners.

Further Improvements that ought to be made to secure the Greater Public Benefit, if such Extensive Rebuilding is undertaken at Public Expense. — While studying this canal I was very forcibly struck by the fact that when two vessels of the largest class now frequenting the canal are lying abreast of each other at the wharves on opposite sides of the canal, there is practically no room for another vessel to pass up to, or go to sea from, a berth at a point above them; and if the canal is reconstructed *with the increased depth of water proposed*, the size of the vessels coming there will undoubtedly be larger and consequently wider than those that frequent the canal to-day, and in that case they may not even be able to lie abreast of each other.

For this reason, it seems to me that, if so large a sum of money is to be expended by public authorities in reconstructing the canal, every means should be taken to secure the greatest possible public benefit therefrom; and in order to do this, the canal should be widened sufficiently to enable a vessel to pass up or down the canal even when the wharves on both sides below it are occupied by vessels. This might be accomplished in the following manner: Wherever a new quay is constructed, it should be built at such a distance back from the present line of the canal that when a similar wall is built on the opposite side the distance between them will be 120 to 140 feet. This would increase the cost of the construction of each linear foot of the new wall by from 30 to 50 cents for each foot gained in width of canal, this being practically the cost of dredging out and disposing of the extra material. To this should be added the damage caused to the wharf by decreasing its area.

Wider Drawbridges. — In order to get the greatest benefit from the proposed changes in the Broad canal, it would also be necessary to increase the width of draw openings in the bridges over Broad canal, but I have made no estimate of the cost of this, as it is a matter which may be demanded to accommodate vessels at any time in the future, even if no dam is constructed. In that case, it would have to be done by and at the expense of the city of Cambridge, and so it does not seem to me to be an item which should be properly included here.

Lechmere Canal.

General Description. — The Lechmere canal is in many ways similar to the Broad canal, but is much shorter. The lower portion adjoining the Charles basin was planned to be 100 feet wide, while the upper portion, running up generally parallel with the river, was planned to be 120 feet wide. The salient angle at the junction of the two portions of the canal has been cut off, to enable vessels to readily turn the corner and pass from one section to the other. The Lechmere canal has a depth of from 4 to 5 feet at mean low water for the outer 500 feet adjoining the Charles basin; thence the depth gradually decreases, until at the upper end the bottom of the canal is practically at mean low water.

The northerly side of the canal, bordering on Bridge Street, has been built up for many years. The southerly side of the outer portion has only recently been built up, and is being reclaimed from the tidal basin to be occupied as a city park.

At the time the sea wall now standing here bordering the park land was licensed to be built, there was objection made by the owners of the

wharves along the northerly side of the canal that it would be exceedingly difficult, if not impossible, for vessels to freely pass into and from the canal unless the sea wall was set back more than the 100 feet from the northerly line; and the city acceded to their request, setting back the wall so that the distance between the wall on the northerly side and the sea wall of the city park is 120 feet, excepting for a short space at Commercial Avenue, where it is proposed to construct a highway bridge across the canal.

The sea walls on the northerly side of this Lechmere canal are substantially the same as those on the southerly side of Broad canal; and, in order to excavate the canal to the depth required to meet the specification presented by Mr. Pillsbury on behalf of the property owners, it will be necessary to remove the north wall entirely, and replace it by a more substantial structure.

The wharves along the westerly side of the inner section of the Lechmere canal are filled solid, and the filling supported by timber bulkheads. On the southerly side of the outer portion of the canal at the city park the sea wall has been built, but the filling has not as yet been placed back of it. This wall rests on piles, and, with a little additional ballast in front and a reinforcing platform in the rear, the additional dredging necessary in the canal can be done without removing the wall. The balance of this side of the canal has not as yet been built up, and I have made no estimates for any work to be done here.

Nearly the whole length of the north and west sides of the Lechmere canal is used for discharging cargo from vessels; and for this reason I have estimated for replacing the wall and bulkhead on the northerly and westerly sides of the canal its whole length, and for dredging it to the depth specified in the proposition presented by Mr. Pillsbury on behalf of the owners. I do not see how this work can be materially changed if the owners are to have at least equal facilities after the dam is built to those now enjoyed by them.

There are two docks leading from the northerly side of the Lechmere canal, both very shallow, and I have made my estimates on the basis that these would be filled up, for this land is probably more valuable than this water space.

Estimate No. 3. (Lechmere Canal.)

Dredging 48,000 cubic yards, at 30 cents, ...	$14,400
Walls and bulkheads: —	
1,000 feet to be removed and rebuilt, at $40, . .	40,000
900 feet to be removed and rebuilt, at $37, . .	33,300
300 feet to be strengthened, at $8, ...	2,400
Rebuilding sewer siphon, ...	1,200
	$91,300
Incidental expenses and supervision, 10 per cent., . .	9,100
Total for Lechmere canal, ...	$100,400

Since no structures have been built on the southerly and easterly sides of the Lechmere canal, except just at the entrance, where the wall has been set back 20 feet from the original width of the canal, it seems to me that if anything is done here it should be with the special agreement that the canal, throughout its length except at Commercial Avenue, should be not less than 120 feet wide, with the corner at the angle cut off, as shown on the plans of the Cambridge Improvement Company, — and a greater width would be better.

Recapitulation of Costs, estimated to meet the Specification of Property Owners, as presented by Mr. Pillsbury.

Broad canal and approaches, Estimate No. 1, ...	$231,365
Lechmere canal, ...	100,400
Total for both canals, ...	$331,765
Capitalized cost of continual breaking up of ice, at $4,000 per year, at 4 per cent., ...	100,000
Total, ...	$431,765

If Broad canal has walls rebuilt only where used for shipping, and the remainder protected by riprap on the dredged slope, the cost will be reduced by Estimate No. 1 less Estimate No. 2, $64,038.

Respectfully submitted,

FRANK W. HODGDON,
Civil Engineer.

Appendix No. 13.

Estimates of Cost of Rebuilding Craigie Bridge.

Dec. 19, 1902.

President Henry S. Pritchett, *Chairman, Committee on Charles River Dam.*

Dear Sir: — In compliance with your request for information concerning the canal or Craigie bridge, and for estimates of the cost of reconstructing the same, the following statement and the enclosed estimates have been prepared.

The bridge was originally built in 1808, rebuilt in 1852, and again rebuilt and widened in 1874. It is a wooden pile structure, with a wooden swing draw. The general condition of the bridge is poor and nearly beyond repair, and it should be replaced with a more permanent structure in the near future.

It is understood that these estimates are approximate only.

Yours respectfully,

WILLIAM JACKSON,
City Engineer.

Plan No. 1.

Deck bridge, 70 feet wide, with stone paved roadway and asphalt sidewalks. Steel girder spans and steel draw of the double retractile type. Stone piers and abutments; draw foundation and pier, etc., to be pile structures. Grade of bridge, 23 feet above Boston base, and level between abutments. Maximum headroom above mean high water (at draw), 7.5 feet.

Removing old bridge, etc.,	$6,000
Masonry piers and abutments,	290,000
Superstructure,	331,100
Draw foundation, piers, etc.,	42,350
Approaches, construction,	38,750
	$708,200
15 per cent. for engineering and contingencies,	106,230
	$814,430
Grade damages,	50,000
Total,	$864,430

Plan No. 2.

Deck bridge, 100 feet wide. Same construction as Plan No. 1. Grade of bridge, 23 feet at abutments, and 25.5 feet at draw. Maximum headroom above mean high water (at draw), 8 feet.

Removing old bridge,	$6,000
Masonry piers and abutments,	385,700
Superstructure,	462,204
Draw foundation, piers, etc.,	45,650
Approaches, construction,	50,410
	$949,964
15 per cent. for engineering and contingencies,	142,494
	$1,092,458
Grade damages,	56,000
Total,	$1,148,458

PLAN NO. 3.

Deck bridge, 100 feet wide, with stone paved roadway and asphalt sidewalks. Steel girder spans and steel swing draw. Stone piers, abutments and draw foundation. Grade from Prison Point Street, Cambridge, at 23 feet, to draw at 38.5 feet, maximum 2 per cent. From draw to present grade of Leverett Street at Brighton Street, maximum 3 per cent. Maximum headroom above mean high water (at draw) 23 feet.

Removing old bridge,	$6,000
Masonry piers and abutments, including draw foundation,	454,000
Superstructure,	515,500
Approaches, construction,	114,380
	$1,089,880
15 per cent. for engineering and contingencies,	163,482
	$1,253,362
Grade damages,	210,000
Total,	$1,463,362

PLAN NO. 4.

Ornamental bridge, 100 feet wide, with stone paved roadway and asphalt sidewalks. Twelve deck spans and one through span for headroom under bridge. Grades and approaches same as for plan No. 3. Maximum headroom above mean high water (under through span), 23 feet.

Removing old bridge,	$6,000
Masonry piers and abutments,	820,000
Superstructure,	585,000
Approaches, construction,	184,380
	$1,595,380
15 per cent. for engineering and contingencies,	239,307
	$1,834,687
Grade damages,	210,000
Total,	$2,044,687

Appendix No. 14.

Estimated Cost of Separation of Storm Water from Sewage in Cambridge Sewers

IN

DISTRICTS TRIBUTARY TO CHARLES RIVER.

By Lewis M. Hastings, *City Engineer.*

Office of the City Engineer, Cambridge, Mass.,
Nov. 7, 1902.

Mr. John R. Freeman, C.E., *Engineer Committee on Charles River Dam.*

Dear Sir: — Agreeable to your request, I have examined the matter of the construction of a separate system of sewers to take the sewage from the districts now having a storm discharge into the Charles River above the outlet of the Bridge Street sewer. I have not had time to make an extended or careful study of the question, but have used such data as have been available in the office, which have been fairly complete.

From the plans on file a complete system of separate sewers has been designed, covering the territory in question and discharging into the Cambridge branch of the metropolitan sewer at 20 points along the line. The sewers as designed vary in size from 8 inches in diameter to 26 inches by 30 inches interior dimension. The average depth ranges from 9 feet to 10 feet. It would be necessary to place a number of these sewers upon a pile foundation, and this has been estimated separately. The total length of sewers included in this scheme is 401,900 lineal feet, or 76.12 miles. The total estimated cost for constructing these sewers is $767,783.50, or an average of $1.91 per lineal foot.

As the separation of the sewage from the storm water will involve in most cases the reconstruction of the present plumbing arrangements in nearly all the houses within the district, I have obtained an estimate of the number of houses which will be likely to be affected. This estimate is made up partly from data procured from the board of assessors, whose figures refer to the conditions existing on May 1, 1902, and partly from counts taken from plans made up to May 1, 1901. The number of buildings obtained in this manner in the district above referred to is 11,232.

I have talked with a plumber who has had considerable experience in the plumbing of houses in Cambridge about the probable cost of making the necessary alterations in the average house, to separate the sewage from storm water. While this amount would undoubtedly vary greatly in the individual cases, his judgment was that $100 might fairly

be taken as about the average cost, and I think this would be as near an estimate as could be obtained. On this basis the total cost of completing the separation of the private sewerage systems would be $1,123,200.

Very respectfully,

L. M. HASTINGS,
City Engineer.

OFFICE OF THE CITY ENGINEER, CAMBRIDGE, MASS.,
Nov. 11, 1902.

MR. JOHN R. FREEMAN, C.E., *Engineer Committee on Charles River Dam.*

DEAR SIR: — Your favor of Nov. 8, 1902, is received, and in response to your request I have had a division made in the estimate already sent you, of the cost of the separate sewers which are within the territory having a storm discharge at the Binney Street sewer outlet.

I find the area as at present sewered in this district to be 720.8 acres, and that it would require 149,350 feet of sewers, varying in size from 8 inches to 18 inches in diameter.

The estimated cost of constructing these sewers is $259,858.50. If it should be found feasible to delay the construction of the separate system in this district, of course the estimate which I forwarded to you would be reduced by this amount, and would leave a balance of $507,925 as the estimated cost for sewering the upper section of the city.

I have also obtained, from the same data as before, the number of buildings in the Binney Street district referred to above, and find that there are about 5,199, giving a balance of 6,033 on the upper section of the city.

I trust these figures will serve your purpose.

Very respectfully,

L. M. HASTINGS,
City Engineer.

Appendix No. 15.

Cost of Diversion of Boston Sewage from the Charles.

INTRODUCTION OF THE SEPARATE SYSTEM OF SEWERS, ETC.

Condensed from a report by Louis F. Cutter, *C.E.*, Assistant Engineer, City Engineer's Department, City Hall, Boston.*

John R. Freeman, *Chief Engineer.*

Dear Sir: — You requested me to make an estimate of the cost of carrying out the following propositions: —

A. The cost of separation of sewage from storm water by means of the introduction of the so-called "separate system" of sewerage throughout that portion of Boston tributary to the Charles River above the site of the proposed dam, in order that the storm water entering the Charles may no longer be polluted by mixture with sewage.

I find that to carry this out completely there would have to be expended upon sewers and drains within the public streets about $3,151,000, while in addition there would probably have to be expended in changing over the house drains and house plumbing, so as to separate the roof water from the sewage proper, the further sum of $1,554,000; the total expenditure involved would therefore be $4,705,000.

B. A partial separation of storm water from sewage, this differing from the above, by omitting, for houses already built, to change over the plumbing and the house drains as called for under *A*, while insisting upon this separation in the plumbing of all future buildings.

I find, while this is practicable and would at first view appear to effect a large saving, it would by no means save the whole of the $1,554,000 estimated for changing house drains in item *A*. The reason for this is that many of the house drains would have to be altered in establishing the separate system, irrespective of roof water, and some of the new separate sewers would have to be planned somewhat larger, because of including the roof water. Moreover, within the older and more thickly settled part of Boston the roof area comprises about 45 per cent. of the entire area, and to this must be added say 10 per cent., to allow for private catch-

* By the courtesy of Mr. William Jackson, city engineer, Mr. Cutter was given temporary leave of absence from his regular duties, that he might undertake this work for the committee on Charles River dam.

basins draining paved back yards. This is by far the most impervious, non-absorptive and most quickly drained part of the entire area, and delivers a large volume to the sewers. Therefore, in these very thickly built regions it would not appear advisable to continue to admit roof water to the present house drains after a separate system of sewers is instituted. Within Brighton and much of the Stony Brook territory the proportion of roof area is very much smaller, and it would be feasible, and perhaps best, to avoid imposing on householders in those districts this great expense of changing over the roof connections and house drains.

C. Introduction of Separate System in the "High-level" District. — The new high-level sewer to be completed two years hence is designed to receive ultimately sewage only, and the law provides that all districts tributary to it in which sewers have not already been constructed must be sewered on the separate system.

This sewer will serve Newton, Waltham and Watertown, already sewered on the separate system, but will also serve large areas in Brookline, Brighton and in the Stony Brook district of Boston, which are now sewered on the combined system, and which therefore in time of storm would continue to pollute the Charles.

It appeared desirable, therefore, to make a division in the estimate, in order to see what sum would be required for a complete separation in the region tributary to the new high-level sewer. The result is given in the following table, which, in addition, gives separately the cost of introducing the separate system in the areas respectively tributary and not tributary to the proposed intercepting or marginal conduit: —

Estimated Cost of introducing Separate System in Boston Districts now sewered on the Combined System with Overflows Tributary to Charles River Basin.

	In Territory the Sewage of which will be diverted to the High-level Sewer.		In Territory the Sewage of which will not be diverted to the High-level Sewer.		Totals.	
	Amounts.	Totals.	Amounts.	Totals.	Amounts.	Totals.
In Territory Tributary to the Proposed Intercepting Conduit.						
Stony Brook drainage area: —						
Street pipes, etc., . . .	$382,000		$273,000		$655,000	
Changing house connections,	214,000	$596,000	209,000	$482,000	423,000	$1,078,000
City proper: —						
Street pipes, etc., . . .	-		$464,000		$464,000	
Changing house connections,	-	-	462,000	926,000	462,000	926,000
Totals: —						
Street pipes, etc., . . .	$382,000		$737,000		$1,119,000	
Changing house connections,	214,000	$596,000	671,000	$1,408,000	885,000	$2,004,000
In Territory not Tributary to the Proposed Intercepting Conduit.						
Brighton: —						
Street pipes, etc., . . .	$580,000		-		$580,000	
Changing house connections,	193,000	$773,000	-	-	193,000	$773,000
Stony Brook drainage area: —						
Street pipes, etc., . . .	$753,000		$523,000		$1,276,000	
Changing house connections,	222,000	975,000	200,000	$723,000	422,000	1,698,000
Muddy River area: —						
Street pipes, etc., . . .	$176,000		-		$176,000	
Changing house connections,	54,000	230,000	-	-	54,000	230,000
Totals: —						
Street pipes, etc., . . .	$1,509,000		$523,000		$2,032,000	
Changing house connections,	469,000	$1,978,000	200,000	$723,000	669,000	$2,701,000
Grand total, . . .	-	-	-	-	-	$4,705,000

Areas now sewered on the Combined System with Overflows to the Charles River Basin.

	Area Tributary to Proposed Intercepting Conduit (Acres).			Area not Tributary to Proposed Intercepting Conduit (Acres).			Total Area (Acres).		
	Tributary to High-level Sewer.	Not Tributary to High-level Sewer.	Totals.	Tributary to High-level Sewer.	Not Tributary to High-level Sewer.	Totals.	Tributary to High-level Sewer.	Not Tributary to High-level Sewer.	Totals.
In Brighton, . . .	–	–	–	1,690	–	1,690	1,690	–	1,690
In Stony Brook drainage area.	527	354	881	1,208	779	1,987	1,735	1,133	2,868
In Muddy River area,*	–	–	–	411	–	411	411	–	411
In city proper, . .	–	549	549	–	–	–	–	549	549
Totals, . . .	527	903	1,430	3,309	779	4,088	3,836	1,682	5,518

* Includes the Back Bay west of the Fens and the part of Roxbury and West Roxbury tributary to the Brookline sewers.

D. A Marginal Conduit Plan combined with Separation. — After studying the complete separation in all parts of the district tributary to the Charles basin, it appeared that a large saving in expense, as compared with the cost of complete separation, could be made by allowing the sewers, drains and overflow channels to continue as now throughout that portion of the territory lying east of the Fens and Stony Brook and in part bordering on the Charles and diverting the polluted storm overflows from the combined sewers in this territory into an intercepting conduit or marginal channel, which should begin at the present old Stony Brook gate house in the Fens and extend down stream to just below the proposed dam. It was assumed that the old Stony Brook conduit would be rebuilt.

Very complete estimates showed that a conduit having a capacity of 700 cubic feet per second (about 16 feet wide by 16 feet high, with slope of about one foot per mile) would have conveyed all of the storm water in almost every storm save only the worst one of the average year, without overflow, from this territory of 1,430 acres, and would cost about $867,000 complete from Fens gate house to dam; while a reconstruction and separation of the sewerage and drainage system in the same district (without excluding the street wash from the basin) would cost for work in the streets about $1,119,000; and for new house connections and plumbing about $885,000, — a total of $2,004,000; showing a saving of about $1,137,000 by the marginal conduit plan.

The ultimate saving would not be quite so great as this, for, of the cost of separation, $596,000 was for districts tributary to the high-level sewer in which separation should ultimately be made, even if the marginal conduit should be built. Allowing for this, the saving is $541,000; but there is also the advantage of excluding from the basin the street wash of a populous and heavily travelled district.

Sewage pollution from the remaining 4,088 acres now sewered on the combined system can be obviated by the adoption of the "separate system," at a cost of $2,701,000. Of this amount, $773,000 is for completing the separate system in the 1,690 acres of Brighton territory now

sewered principally on the combined system, and $230,000 for complete separation throughout the 411 sewered acres of the Muddy River area. Both these areas will be tributary to the high-level sewer, and in both the separate system is already in course of introduction. To establish the separate system throughout the 1,987 acres of Stony Brook territory now sewered on the combined system and not included in the 1,430 acres reckoned as tributary to the proposed marginal conduit will cost $1,698,000, of which $975,000 is for the 1,208 acres tributary to the high-level sewer, and $723,000 for the 779 acres that will remain tributary to the present intercepting system.

The operation of the high-level sewer, the much-needed rebuilding of the "old channel" of Stony Brook, and certain comparatively inexpensive expedients, notably the "12-foot channel" proposed by the sewer division, or the still less costly substitute proposed by the city engineer, will, in connection with the marginal conduit, greatly decrease the amount and the harmfulness of sewage pollution from the Stony Brook area, both as regards the Charles and as regards the pond in the Fens, and, in my opinion, if properly co-ordinated, will postpone for many years the need of changing to the separate system in the Stony Brook area.

E. The study was begun concerning the feasibility and cost of so lessening the present unrestricted influx of storm water from the Church Street district and certain other low districts into the main drainage sewers that this storm water should not longer be sufficient to crowd out the sewage into the Charles through the overflows from other districts.

While this appears feasible, there has not been found time to prepare a full analysis of the problem; and, with the marginal conduits as finally recommended, this problem becomes of less urgent importance.

Method of estimating Cost of Separation of Storm Water from Sewage.

As there was not time to make a design for drains * throughout the 205 miles of streets in the 5,518 acres of territory under discussion, a more rapid and less exact method had to be adopted.

Cost per Foot of Street in Typical Districts. — To carry out the separation in a thoroughly efficient manner requires two distinct classes of expenditure, varying according to different laws, and for that reason estimated separately: (*a*) the cost of building new drains or sewers in the public streets; (*b*) the cost of changing the house branch sewers where necessary to connect with a new sewer, the connection of roof-water pipes and area drains with the storm-water drain, and such changes in the interior plumbing of buildings as may be necessary to effect this separation. The cost of (*a*) depends chiefly upon the length of street; the cost of (*b*) does not depend at all on the length of street, but chiefly on the number of houses and the arrangement of the plumbing.

As a guide to the cost of changing the street pipes, three districts were selected which were thought to be typical, respectively, of the West End, the Back Bay and the Stony Brook area. A system of drains was devised for each of these districts, which, with the existing sewers, would constitute a separate system. The cost of this whole district system was then estimated, and from it the average cost per linear foot

* The word "drain" signifies a conduit for storm water or ground water; "sewer," a conduit for sewage.

of street in the typical district was computed. This cost per linear foot was then multiplied by the number of feet of street in other districts where the conditions were thought to be similar; but if, in another district, any condition was known that would tend to increase or diminish the cost, the factor was modified accordingly.

This method by analogy from typical districts was followed in estimating the cost of the street conduits, including man-holes and connections with the existing street catch-basins, but a somewhat different method was followed in estimating the cost of changing the house connections and of connecting the roof-water pipes with the drains, and the same method was not followed for house connections in all of the various districts. In the West End a small typical area of about 6 acres, containing 125 houses, was selected, and the cost of changing the house connections and roof-water pipes was estimated in detail; the average cost per acre was then applied, with modifications, to the rest of the Cambridge Street district; the average cost per foot of street in that area was calculated, and applied, with modifications, to the rest of the West End territory. In the Back Bay the cost of making the changes was computed for a block containing 49 houses, and the average cost per house* was computed, and multiplied by the number of houses in the Berkeley Street district of about 90 acres. The average cost per foot of street in that district was then computed, and applied, with modifications, to the street length of the other Back Bay districts.

In the Stony Brook area a similar method was first tried; but the number of houses per acre varied so greatly in the different parts of that area that an actual count of houses throughout the district was made, and the number of houses was multiplied by the estimated average cost per house.

The three typical districts chosen for getting at the cost of the street conduits were: for the West End, the district tributary to the sewer in Cambridge Street (called the Cambridge Street district); for the Back Bay, the district tributary to the sewer in Berkeley Street (Berkeley Street district); and for the suburban portion of the Stony Brook area, the district tributary to the sewer in Columbus Avenue above Ritchie Street (Columbus Avenue district). This last is a suburban residence district adjacent to Franklin Park.

Table I. shows the acreage, length of street, estimated cost of street conduits and estimated cost of house connections in the three typical districts, and gives also, separately, the cost of street conduits and of house connections per acre and per linear foot of street, and the average length of street per acre.

Tables II., IV. and V. show the application of the average costs of street conduits per foot of street in the typical districts, to the street length of other districts. The districts are designated by letters or numbers, which refer to the map. The variations in the factors are due, in the city proper, principally to differences in the paving, depth of excavation, pipes, etc., to be encountered, and water to be pumped. In Roxbury, West Roxbury and Brighton the differences are due principally to variations in the amount of rock that is likely to be encountered in the excavations. The factors assumed for the districts in Brighton are based on the estimated cost of changes in the Columbus Avenue district, no separate estimate having been made for a typical Brighton district.

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* Changes in the estimated cost per house were made when it was seen that the expense would be more or less than in the block selected for estimate.

Table III. shows the acreage and number of houses in the part of the Stony Brook drainage area that is sewered on the combined system, and in those portions of the sewered territory that are tributary and not tributary to the old channel of the brook, and in those portions the sewage of which will and will not be diverted to the high-level sewer; also in the portion that is tributary both to the old channel and to the high-level sewer.

Description of the Estimates for the Typical Districts.

In each of the typical districts a design was made for a system of conduits, which, with the existing sewers and drains, would constitute a separate system of sewerage. This design was made sufficiently detailed and sufficiently exact to give the length and approximate size of the conduit in each street, the approximate depth of excavation and the number of man-holes, and a note was made of the kind of pavement that would have to be replaced. Generally, it was planned to use the present sewer for the sewage, and to make a new conduit for the storm water; but in some cases, where the existing sewer is flat-bottomed and unsuitable for a sewer on the separate system, or where the existing sewer is much larger than would be required for the sewage alone, it was designed to use the present sewer for the storm water, and to make a new conduit for the sewage. This was done in some cases even where the existing sewer is not sufficiently large for the flow of storm water that may be expected in the greatest storms.

The present sewer takes both sewage and storm water, and it did not seem that, where the present sewer is too small, the cost of fitting it to serve as a safe and ample drain for extraordinary rainfalls was fairly chargeable as a part of the cost of introducing the separate system.

However, where the design called for a new storm-water conduit, it was generally designed large enough for the greatest flow that is to be anticipated.

Where it was planned to build new sewers, they were designed for a population of 500 to the acre, and the maximum flow was taken at .0003 cubic feet of sewage per second for each person, which includes an allowance for ground water.

This is equivalent to a depth of .15 inch per hour from the territory sewered. *The density of population assumed is much greater than any now existing in the territory under consideration*, and corresponds to that now found in the most thickly peopled parts of Boston,* but to provide for possible concentration of population on small areas it seemed best to adopt it. The minimum diameter adopted for street pipes was 8 inches.

Conduits 18 inches or less in diameter were designed to be of vitrified earthen pipe, and the cost was estimated at the discount from list price prevailing in Boston in November, 1902, namely, 60 per cent. discount. Conduits 20 and 24 inches in diameter were planned to be of "double-strength" earthen pipe, at a discount of 40 per cent. from list.

For all pipe sewers the cost of Y branches every 25 feet on each side was included in the estimate.

Where it was thought that much water would be encountered, an underdrain was included, and in soft ground a platform and gravel filling.

* In the census of 1890 the population per acre in four of the most densely populated voting precincts was found to be: North End, — ward 7, precinct 2, 404 people to the acre; ward 7, precinct 1, 343 people to the acre; ward 7, precinct 5, 303 people to the acre. South End, — ward 6, precinct 2, 344 people to the acre.

For conduits over 24 inches in diameter it was planned to use brick-work, at a cost of $16 per cubic yard: and the same price was used in estimating the cost of the brickwork of man-holes. Iron covers and frames for man-holes were estimated to cost $10 per set.

The cost of excavation, not including rock work, was estimated at $1 per cubic yard for a trench 9 feet deep, increase or diminution in the estimated unit cost being made where the depth was greater or less than nine feet.

In the Columbus Avenue district, Roxbury, this price was thought sufficient to include the resurfacing of the streets, which are mostly macadam, but in the city proper an additional allowance was made for replacing the paving. This allowance varied according to the kind of paving. Where a large amount of water was anticipated, an additional allowance was made to cover the cost of pumping it.

The amount of rock to be excavated was ascertained in some cases from the records of the existing sewers, but in most cases these records were incomplete, and the amount of rock had to be estimated from surface indications. The extra cost of rock excavation was estimated at $4.50 per cubic yard.

Tables VI. to XVII. show the length, size and estimated cost of the conduits called for in each street in the three typical districts.*

In the Cambridge Street and Berkeley Street districts, after the cost of street conduits had been computed, it was found that the cost of house connections could be lessened by providing certain additional street pipes. The cost of these pipes was therefore calculated and included in the estimate for house connections.

Table I. — *Estimated Cost of introducing Separate System in Typical Areas in West End, Back Bay and Roxbury.*

	Symbol.	Cambridge Street District (West End).	Berkeley Street District (Back Bay).	Columbus Avenue District (Roxbury).
Acreage, ...	A	53	89.7	190
Linear feet of street, ...	B	20,400	24,500	35,250
Linear feet of street per acre, . .	B÷A	385	273	186
Cost of separation, not including house connections.	C′	$50,981 00	$79,605 00	$124,525 00
Cost per acre, not including house connections.	C′÷A	962 00	887 00	655 00
Cost per linear foot of street, not including house connections.	C′÷B	2 50	3 25	3 53
Cost, not including house connections, and without rock excavation.	-	-	-	85,557 00
Per linear foot of street if without rock excavation.	-	-	-	2 43
Cost of changing house connections,	C″	77,710 00	61,361 00	28,083 00
Cost per acre of changing house connections.	C″÷A	1,466 00	684 00	148 00
Cost of changing house connections per linear foot of street.	C″÷B	3 81	2 50	80

* These twelve tables are omitted from the printed report.

TABLE II. — *City Proper and Muddy River. — Estimated Cost of introducing Separate System in Sewered Territory Tributary to Charles River Basin.*

DISTRICT (LETTERS REFER TO A MAP NOT REPRODUCED).	A. Area Sewered (Measured on Map).	B÷A. Length of Street per Acre (Calculated from A and B).	B. Length of Street in District (Measured on Map).	C′÷B. Estimated Cost, per Foot of Street, of Street Pipes, etc., for Separate System (Estimated from Table I.).	C′. Cost of Street Pipes, etc., for Separate System (Calculated from B and C′÷B).	ESTIMATED COST OF CHANGING HOUSE CONNECTIONS AND PLUMBING. C″÷B. Per Foot of Street (Estimated from Table I.).	C″. Total (Calculated from B and C″÷B).	C=C′+C″. Total Cost of Introducing Separate System.
City Proper: —	Acres.	Feet.	Feet.					
L, not including park,	13	542	7,040	$2 60	$18,300	$3 90	$27,500	$45,800
K, not including park,	73	240	24,800	2 40	59,500	3 70	91,800	151,300
J, not including Common,	52	331	17,200	2 50	43,000	3 30	56,800	99,800
I, not including Public Garden,	58	377	21,840	2 90	62,300	3 60	78,600	140,900
H,	94	243	22,800	3 25	74,100	2 50	57,000	131,100
G,	65	255	16,560	3 25	53,800	2 70	44,700	98,500
F,	70	200	14,000	3 25	45,500	2 60	36,400	81,900
D,	124	267	33,040	3 25	107,400	2 20	69,400	176,800
Muddy River: —								
C,	175	160	28,000	2 80	78,400	(0 57)	15,700*	94,100
B,†	23	296	6,800	(1 80)†	12,200	(0 47)	3,200‡	15,400
A,†	175	205	35,900	(1 80)†	64,600	(0 71)	25,600§	90,200
M,	38	189	7,360	2 90	21,300	(1 28)	9,400‖	30,700
Totals and averages,	960	245	235,340	$2 72	$640,400	$2 19	$516,100	$1,156,500
Total for city proper,¶	549	-	157,280	-	463,900	-	462,200	926,100
Total for Muddy River,**	411	-	78,060	-	176,500	-	53,900	230,400

* 157 houses at $100. † Separate system already partly introduced. ‡ 32 houses at $100. § 366 houses at $70. ‖ 118 houses at $80.
¶ Tributary to proposed intercepting conduit. ** Not tributary to intercepting conduit; sewage will be diverted to high-level sewer.

TABLE III. — *Stony Brook Drainage Area. — Portion Sewered on Combined System; Acreage and Number of Houses.*

District (Numbers, etc., refer to a Map, not Reproduced.)	Area Sewered (Measured on Map).	Sewered Area Tributary to Old Channel.	Sewered Area not Tributary to Old Channel.	Sewered Area Tributary to High-level Sewer.	Sewered Area not Tributary to High-level Sewer.	Tributary to High-level Sewer and to Old Channel.	Number of Houses (Counted on Atlas).	Number of Houses in Territory Tributary to Old Channel.	Number of Houses in Territory Tributary to High-level Sewer.*	Number of Houses in Territory Tributary to High-level Sewer and to Old Channel.*
	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.				
E, . .	11	11	–	11	–	11	20	20	20	20
1, . .	91	91	–	91	–	91	300	300	300	300
2, . .	183	183	–	183	–	183	1,010	1,010	1,010	1,010
3, . .	42	42	–	–	42	–	296	296	–	–
4, . .	69	69	–	–	69	–	705	705	–	–
5, . .	58	58	–	–	58	–	430	430	–	–
6, . .	42	42	–	2	40	2	402	402	20	20
7, . .	107	107	–	10	97	10	1,008	1,008	94	94
8, . .	145	–	145	36	109	–	807	–	200	–
9, . .	27	–	27	23	4	–	185	–	158	–
10, . .	132	132	–	84	48	84	840	840	534	534
11, . .	4	–	4	–	4	–	52	–	–	–
12, . .	83	–	83	53	30	–	409	–	262	–
13, . .	23	–	23	–	23	–	120	–	–	–
14, . .	58	–	58	11	47	–	392	–	73	–
15, . .	249	–	249	188	61	–	710	–	535	–
16, . .	45	–	45	3	42	–	182	–	12	–
17, . .	119	–	119	13	106	–	466	–	51	–
18, . .	186	–	186	105	81	–	615	–	344	–
19, . .	119	–	119	62	57	–	360	–	187	–
20, . .	51	–	51	–	51	–	132	–	–	–
21, . .	234	–	234	234	–	–	459	–	459	–
22, . .	16	–	16	16	–	–	75	–	75	–
23, . .	31	–	31	15	16	–	29	–	15	–
24, . .	597	–	597	449	148	–	1,117	–	840	–
25, . .	146	146	–	146	–	146	1,123	1,123	1,123	1,123
Totals,	2,868	881	1,987	1,735	1,133	527	12,244	6,134	6,312	3,101
Cost of changing house connections, assuming an average cost of $69 per house, including $9 for engineering and inspection.							$845,000	$423,000	$436,000	$214,000

* Approximate: Where a district is partly tributary and partly not tributary to the high-level sewer the number of houses tributary to that sewer is assumed to be proportional to the tributary area.

TABLE IV. — *Stony Brook Drainage Area. — Estimated Cost (not including House Connections) of introducing Separate System.*

District (Numbers, etc., refer to a Map not reproduced).	A. Area Sewered (Measured on Map).	B÷A. Length of Street per Acre (Calculated from A and B).	B. Length of Street in Sewered Area (Measured on Map).	C'÷B. Estimated Cost, per Foot of Street, of Street Pipes, etc., for Separate System (Estimated from Table I.).	C'. Cost of Street Pipes, etc., for Separate System (Calculated from B and C'÷B).	Cost of Street Pipes, etc., for Separate System. In Territory Tributary to the Old Channel of the Brook.*		In Territory the Sewage of which will be diverted to the High-Level Sewer.		In Territory Tributary to the Old Channel,* and of which the Sewage will be diverted to the High-Level Sewer.	
	Acres.	Feet.	Feet.			Acres.	Cost.	Acres.	Cost.†	Acres.	Cost.
E,	11	255	2,800	$3 00	$8,400	11	$8,400	11	$8,400	11	$8,400
1,	91	182	16,640	3 00	49,900	91	49,900	91	49,900	91	49,900
2,	183	220	40,240	3 10	124,700	183	124,700	183	124,700	183	124,700
3,	42	261	10,960	3 00	32,900	42	32,900	-	-	-	-
4,	69	246	16,960	3 00	50,900	69	50,900	-	-	-	-
5,	58	262	15,200	3 20	48,600	58	48,600	-	-	-	-
6,	42	267	11,200	2 95	33,000	42	33,000	2	1,600	2	1,600
7,	107	259	27,760	3 00	83,300	107	83,300	10	7,800	10	7,800
8,	145	223	32,320	3 30	106,700	-	-	36	26,400	-	-
9,	27	252	6,800	3 50	23,800	-	-	23	20,300	-	-
10,	132	206	27,120	3 50	94,900	132	94,900	84	60,500	84	60,500
11,	4	500	2,000	3 00	6,000	-	-	-	-	-	-
12,	83	197	16,200	3 40	55,100	-	-	53	35,100	-	-
13,	23	216	4,960	3 00	14,900	-	-	-	-	-	-
14,	58	225	13,040	3 10	40,400	-	-	11	7,500	-	-
15,	249	210	52,360	3 50	183,300	-	-	188	138,200	-	-
16,	45	196	8,800	3 40	29,900	-	-	3	2,000	-	-
17,	119	203	24,160	3 30	79,700	-	-	13	8,700	-	-
18,	186	216	40,160	3 20	128,500	-	-	105	72,600	-	-
19,	119	207	24,640	3 50	86,200	-	-	62	44,800	-	-
20,	51	149	7,600	3 20	24,300	-	-	-	-	-	-
21,	234	112	36,120	3 00	108,400	-	-	234	108,400	-	-
22,	16	215	3,440	2 50	8,600	-	-	16	8,600	-	-
23,	31	187	5,800	3 00	17,400	-	-	15	8,400	-	-
24,	597	202	120,880	3 00	362,600	-	-	449	272,700	-	-
25,	146	250	36,760	3 50	128,700	146	128,700	146	128,700	146	128,700
Totals and averages,	2,868	211	604,920	$3 19	$1,931,100	881	$655,300	1,735	$1,135,300	527	$381,600
Average cost per acre,	-	-	-	-	$673	-	$744	-	$654	-	$724

* Tributary to proposed intercepting conduit. † Assumed to be proportional to area in districts partly tributary and partly not tributary to high-level sewer.

TABLE V. — *Brighton. — Estimated Cost of introducing Separate System in Sewered Districts in Brighton.*

DISTRICT (NUMBERS REFER TO A MAP NOT REPRODUCED).	A. Area Sewered (Measured on Map).	B÷A. Length of Street per Acre (Calculated from A and B).	B. Length of Street in Sewered Area (Measured on Map).	C′÷B. Estimated Cost, per Foot of Street, of Street Pipes, etc., for Separate System (Estimated from Table I.).	C′. Cost of Street Pipes, etc., for Separate System (Calculated from B and C′÷B).	Number of Houses (Counted on Atlas).	C″. Estimated Cost of Changing House Connections and Plumbing (2,793 Houses at $69).	C=C′+C″. Total Cost of Introducing Separate System.
	Acres.	Feet.	Feet.					
1, ...	77	88	6,800	$2 40	$16,300	Not counted by districts.	-	-
2, ...	44	185	8,160	2 50	20,400		-	-
3, ...	499	103	51,200	2 80	143,400		-	-
4, ...	313	180	56,400	2 50	141,000		-	-
5,*	130	169	22,000	1 75*	39,000		-	-
6,*	34	134	4,560	1 80*	8,200		-	-
7,*	148	103	15,280	1 40*	21,400		-	-
8, ...	236	191	45,120	2 40	108,300		-	-
9, ...	133	162	21,600	2 40	51,800		-	-
11, ...	50	184	9,200	2 40	22,100		-	-
12, ...	26	135	3,520	2 40	8,400		-	-
Totals and averages.	1,690	144	243,840	$2 38	$580,300	2,793	$193,000	$773,000

* The sewers of these districts now operate on the separate system, but surface drains have not been built in all the streets.

The sewered territory north of 9 and east of 8 is already sewered on the separate system, and is not included in this table.

It is believed that the estimates of the cost of new street pipes and conduits needed for the separate system thus made for these large areas by the method of analogy to typical districts are surely within twenty-five per cent. of the truth, supposing present prices to prevail at the time of construction, and as likely to be too large as too small, but the estimates of the cost of changing the house connections are, from the nature of the case, less reliable and may be considerably more than 25 per cent. in error. The result of these estimates is as already presented in table on p. 435.

Separation in New High-level District. — When the high-level intercepting sewer now building by the Metropolitan Sewerage Commission is completed, and when certain branch intercepting sewers have been constructed by the city, the sewage of Brighton and a part of the Stony Brook area will be diverted from the Boston main drainage works, and will flow to a new outlet at Peddock's Island. The law * requires that all drainage areas not already provided with sewers, which may here-

* Chapter 424, section 8, Acts of 1899.

after be tributary to the high-level sewer, shall be sewered on the separate system; and it is a part of the programme proposed by the sewer division of the Boston street department* to introduce the separate system eventually throughout the Boston territory tributary to the high-level sewer, even where such territory is already sewered on the combined system.

If this programme of separation is carried out by the city because of considerations not connected with the Charles River basin, then the cost fairly chargeable to the diversion of sewage from the basin would be the cost of introducing the separate system in the remainder of the Boston territory tributary to the basin. This would be about as given in table on p. 435.

Partial Separation.

Cost of separating Storm Drainage of Streets and Yards, while permitting Roof Drainage to proceed through Present House Connections as now. — The very great cost of changing the existing house connections so as to exclude the roof water from the sewers, and the possible objections of property owners to having their pipes and plumbing interfered with, suggest the inquiry whether a sufficient diversion of storm water might not be made by connecting the brooks and street catch-basins with the storm-water drains, without interfering with private property.

An examination shows that the roof area in the West End is about 42 per cent. of the whole area, in the built-up part of the Back Bay about 32 per cent., and in the Church Street district (exclusive of the Public Garden) about 45 per cent. The private catch-basins in the back yards will probably bring the proportion of storm water reaching the sewers through the house connections to at least 57, 42 and 60 per cent. respectively of the total volume of storm water reaching the sewer.

Under these conditions, it would seem hardly worth while to introduce the separate system, unless the roof and yard water were to be taken into the storm-water drains, for only in very slow rains and thaws would overflows be obviated. In Brighton and the sewered portion of the Stony Brook area, however, the percentages of roof area are about 5 and 12 per cent. respectively of the whole; and here the exclusion of street and surface water, leaving the roofs still tributary to the sewers, would be more effective than in the city proper. The total roof area in the territory sewered on the combined system is in Brighton about 82 acres, and in the Stony Brook area about 324 acres. The proportion of this roof area now connected with the sewers is not known, but may be assumed to be about 80 per cent., or 66 acres in Brighton and 260 acres in the Stony Brook area. Adding the 185 acres of the easterly low districts,† the rainfall of which must be taken care of, a total of 511 acres is obtained. Assuming a maximum flow equal to 75 per cent. of the rainfall, the outfall works will have a surplus carrying capacity at various dates, up to 1940, sufficient to dispose of the flow of Brighton and Stony Brook roof water due to rainfalls of the intensities shown in the following table: —

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* Street department report for 1901.
† Beach, Dover and Dedham streets (see p. 447).

Date.	Surplus Carrying Capacity of Boston Outfall Works.* Cubic Feet per Hour.	Rate of Rainfall that the Surplus Capacity of the Outfall Works will dispose of from Area of 511 Acres, chiefly Roofs, assuming Maximum Flow of 75 Per Cent. of the Rainfall. Inches per Hour.
1905,	512,000	0.37†
1910,	477,000	0.35
1915,	446,000	0.32
1920,	413,000	0.30
1925,	371,000	0.27
1930,	329,000	0.24
1935,	279,000	0.20
1940,	229,000	0.17

* See table on p. 51 of Metropolitan Sewerage Commission's report on high-level gravity sewer, 1899.

† A rainfall at this rate on the 260 acres of roofs of the Stony Brook area would cause overflows, because the carrying capacity (about 65 cubic feet per second) of the Stony Brook branch of the intercepting sewer is not quite sufficient for the resulting flow in addition to the flow of sewage. A slightly slower rainfall, however, would not cause overflows after the diversion of the high-level sewage and the enlargement of the trunk sewers.

The table shows that in 1905 the outfall works can dispose of the roof water due to rainfall not exceeding .37 inches per hour, and in 1940 that due to rainfall not exceeding .17 inches. The former would include the vast majority of all rainfalls of sufficient duration to establish a 75 per cent. flow from districts so scattered as those under consideration. The latter, even, would take in a considerable proportion of the rainfalls; but, as a certain surplus capacity in the outfall works is desirable, in time of storm, to prevent flooding in the low districts other than those at Beach, Dover and Dedham streets, it would not be safe to rely on the present outfall works to dispose of the Brighton and Stony Brook roof water after 1940. The above computation is made on the assumption that none of the roof water will be allowed to enter the high-level sewer, but that regulators will be so arranged as to cause it to flow in channels tributary to the Boston outfall works. If, however, the Metropolitan Commission should allow a portion of the surplus capacity of the high-level sewer to be used in time of storm, to dispose of this roof-water, overflows into the Charles River basin might be obviated in rainfalls of greater intensity than those shown in the table. But the time when other means of disposal of the roof water would have to be adopted could not be delayed much beyond 1940, as the increase of population is expected to exhaust the surplus capacity of the high-level sewer, as well as that of the Boston outfall works, at about that date.

Though the existing roof-water pipes might be allowed to continue tributary to the sewers of the separate system, no new connections ought to be permitted; the roofs of all new buildings should be drained into the storm-water channels. The saving in first cost that can be made by allowing the existing roof connections to continue will not be equal to the amount estimated as the cost of "changing house connections," for the latter includes the cost of disconnecting the house pipes from the present sewers and connecting them with the new sewers, in cases where the present sewer would be used as a storm-water conduit under the separate system. All sewers of the separate system, too, would have to be proportioned for the roof water as well as for the sewage; and that would entail a slight additional expense in the Stony

Brook area, where it is probable that some of the existing trunk sewers, though sufficiently large to carry the sewage, would not be large enough for sewage and roof water.

The result of the inquiry as to roof water may be stated thus: —

In the city proper, the separate system will not be properly effective in preventing overflows of sewage into the Charles unless the roof and yard water, as well as the street water, is excluded from the sewers.

In Brighton and the Stony Brook area, even if the existing roof connections should be allowed to continue tributary to the sewers, the introduction of the separate system will prevent nearly all the overflows in 1905 (after the high-level sewer is in operation), *and thereafter will prevent a considerable but always decreasing proportion of the overflows until 1940.* If the surplus capacity of the high-level sewer is allowed to be used to dispose of a part of the roof water, a still greater proportion of the overflows can be obviated until about 1940; but after that date some other way of disposing of the roof water must be found.

The saving in cost to be had by allowing the present roof-water connections to remain will be less than the estimated cost of "changing house connections," because, (*a*) irrespective of roof water, the house connections must be changed when the present sewer is to be used as a storm-water channel; and (*b*) some of the sewers of the separate system must be built larger for roof water and sewage than would be necessary for sewage alone.

Concerning the Storm Flow from the Unregulated Districts.

In four of the low districts, namely, those tributary to the sewers in Beach Street, Dover Street, East Dedham Street and Church Street, some of the cellars are so low as to be in danger of flooding when a storm occurs at high tide, under the conditions heretofore, unless a large part of the flow resulting from such a storm is taken into the deep intercepting sewers of the main drainage system. With these sewer levels backed up to discharge storm water into the Charles or Fort Point basins at extreme high tide, of 10 or 11, or even 12, feet above city datum, great damage might be caused. The top of the intercepting sewers of the main drainage are at from 5 to 11 feet lower grade.

For this reason, the sewers in Beach, Dover and East Dedham streets, and the sewer draining the Church Street district, have been left to this day unprovided with regulators at their confluence with the intercepter, so that the combined sewage and storm water from these districts in full volume has a free entrance into the Boston main drainage system.

The plan of preventing the overflow of combined sewage and storm water by adopting the separate system, that is, by excluding the storm water from the sewers, will not be wholly effective for preventing the pollution of the Charles unless the intercepting sewers and the pumping and outfall works have a capacity sufficient for the whole flow of sewage, and for such storm water as may enter the intercepting sewers from districts in which the separate system is not adopted.

Except in the low districts, above alluded to, nearly all the storm water due to heavy rainfalls can be excluded from the intercepting sewers by means of the regulators, which are valves or gates arranged to close automatically when the water in the intercepting sewer rises to a certain level.

The Church Street district is tributary to the Charles River basin, and, under the plan now under discussion, its storm water would be excluded from the sewers. But, unless a similar change should be made in the Beach, Dover and East Dedham Street districts, these districts, having an aggregate area of about 185 acres, will continue

to contribute their storm water as well as their sewage to the intercepting system; and it is necessary to determine whether the pumping and outfall works have sufficient capacity to dispose of it in addition to the undiluted sewage of the territory tributary to the Charles River basin.

A computation of this was made, and it was found that, with the high-level sewer in full operation, the storm water of the territory tributary to the Charles separated from the sewage, and thus excluded from the main drainage sewer, and the storm water of the remaining territory (excepting that which comes from the low districts mentioned) excluded by means of the regulators, so much spare carrying capacity and storage room would be left in the main drainage channels that the occasions when this storm water from the low districts could produce overflow into the Charles would be very rare, even with allowance for all probable increase of population up to 1940.

The Marginal Conduit Plan for intercepting Storm Overflows of Mingled Sewage, Street Wash and Storm Water.

The chief objection to lessening the pollution of the Charles from storm overflows by changing from the combined to the separate system of sewers, by excluding the storm water from the sewers, is the great expense. The second great objection is that the street wash would not be prevented from entering the basin.

The great merit of the marginal conduit plan of intercepting the combined sewage and storm water that overflows into the Charles, and conveying it, below the dam, is that the street wash as well as the sewage would be diverted.

To intercept all the storm water discharged in the heaviest rain storm from all the overflows now tributary to the basin would require a conduit so large and so long as to be enormously expensive. The greater the distance from any overflow outlet to the dam, the greater the cost of conveying its discharge to tide water. The more thinly settled the territory, the greater will be the proportion of rain water to sewage in its storm discharge; and consequently the greater will be the cost (if the marginal conduit method is adopted) of diverting each unit of sewage from the basin. It happens that those parts of the territory under consideration that are remote from the dam are also the parts that have the least population. For these districts, comprising Brighton and the southern part of the Stony Brook area, the method of conveying the storm water below the dam appears not to be appropriate.

On the other hand, the overflow outlets from the West End, the Back Bay and the northern portion of the Stony Brook area are comparatively near to the dam, and these districts have a dense population, involving a comparatively large proportion of sewage in the storm discharge. They have also a larger proportion of street area than the more thinly settled districts, and a heavier street traffic, involving more and dirtier street wash. For the West End, then, the Back Bay and the northern part of the Stony Brook area, the method of conveying the overflow discharge below the dam appears likely to be suitable.

The districts the storm water of which it seems most practicable to intercept and discharge below the dam are those having overflows directly into the Charles River basin in the West End, the Back Bay east of the Fens, and the Church Street district, in all, about 549 acres; and those having overflows into the old channel of Stony Brook, about 881 acres, in Roxbury, — a total of about 1,430 acres.

It is not essential that all the storm-water of the greatest storms should be diverted. The entrance of foul water into the basin is not, like the pollution by sewage of a public water supply, a calamity to be

averted at any cost. It is merely an occurrence which, if too frequent or too long-continued, may add unduly to the impurity of the basin.

The problem, then, is to design a conduit sufficiently large to carry off the overflow water due to all rainfalls except extraordinarily severe ones. It will be practicable, in ordinary storms and thaws, as will be explained farther on, to *make the conduit serve other districts than those comprised in the 1,430 acres above mentioned, and so a conduit of liberal capacity has been taken as the basis of the estimate of cost.* A carrying capacity of 700 cubic feet per second was chosen as being one that would be exceeded, on the average, only about once a year by the flow, due to the rainfalls to be anticipated in this locality on the districts comprising the 1,430 acres, strung out and distributed as they are. It is found that such a conduit could be built at a cost considerably less than that of introducing the separate system throughout the 1,430 acres.

To determine how often and to what extent such a conduit might be expected to overflow, a very careful study was made. For many years an automatic record of the rainfall has been kept at the Chestnut Hill reservoir. The instrument there in use records not only the amount and duration of each rainfall, but the rate also at each instant of the storm. Mr. E. S. Dorr, chief engineer of the sewer division of the Boston street department, making use of the Chestnut Hill records of fourteen years, made in 1892 (Boston street department, report for 1892, p. 120) a diagram showing the intensity and duration of all rainfalls (and of all sudden bursts of rain in the course of longer rainfalls) that would be likely to tax the carrying capacity of the sewers.

The diagram shows that rainfalls of great intensity never last very long and that long-continued storms are never of great average intensity. Now, in a drainage area composed of districts so strung out as those under discussion, it is plain that a rainfall of short duration will not cause so great a flow at or near the outlet as a rainfall of long duration and equal intensity; for, in the case of the short rainfall, the water from districts near the outlet will have time to run away before the arrival of the water from the remote districts. In other words, unless the rain continues long enough for the water from the most remote part of the drainage area to reach the outlet, a part only of the drainage area comes into play in contributing to the maximum flow at the outlet, and that part only is to be considered in calculating that maximum flow.* By calculating the time taken by the flood wave in reaching the outlet from each part of the drainage area, it is possible to find out approximately the area contributing to the maximum flow at the outlet, in rainfalls lasting fifteen, thirty, forty-five, sixty and seventy-five minutes respectively; and so (if the percentage of rainfall flowing off is known †) to calculate the intensity of rainfall that a conduit of known

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* This subject is most ably treated in an unpublished report of Mr. Desmond, of the Boston sewer division, on the drainage of the Muddy River valley.

† The weakest point in a calculation of this kind is due to the uncertainty as to percentage of the rainfall that will flow off during the storm. It depends on so many factors, varying as between different districts, and in the same district varying from day to day, and the experimental data are so few, that it is impossible to predict with any certainty. In the above calculation the percentage of roof area (T), the percentage of street area (V) and the declivity of the surface (per 1,000 horizontal) (S) were known approximately for each subdivision of the drainage area, and the percentage of run-off was calculated for each such subdivision by the following formula:—

Percentage of rainfall reaching the sewers during the storm =

$$\frac{\sqrt[5]{S}}{1.38}\Big[70\,(V+A)+25\,(L-A)\Big]+90T,$$

in which L is the area not occupied by streets or buildings, and A is an allowance for paved court yards. The average percentage, thus calculated by districts, for the 1,430 acres, was 62 per cent.

carrying capacity can accommodate, when the rain lasts fifteen minutes, or thirty minutes, or forty-five minutes, or any other length of time. By treating any point on the conduit as the outlet of the territory above that point, the rainfall capacity at any point on the conduit can be calculated for rain lasting for any length of time.

In this way the rainfall capacities of the intercepting conduit at Cambridge Street, at Beacon Street, at Hereford Street and just below Huntington Avenue were calculated for rains of duration varying from five to eighty minutes, and rainfall capacity curves were plotted with duration of rainfall for abscissa and corresponding intensity of rainfall that the conduit can accommodate (rainfall capacity) for ordinate. The curves cross one another, for the conduit at its upper end can accommodate the flow due to rainfalls of greater intensity, if long continued, than at its lower end, owing to the greater area involved in the latter case; while the rainfall capacity *as calculated* of the lower end of the conduit is greater in rains of short duration than that of the upper end. This is due to the sudden widening out of the drainage area above Huntington Avenue, which causes the flow from a broad area to reach the upper end of the conduit at once; while below Huntington Avenue the drainage area is narrow, and the area contributing its flow in fifteen and thirty minutes is much less than at Huntington Avenue.*

A curve was drawn enveloping all these intersecting curves on the lower side (and enveloping of course all curves that might be drawn for points on the conduit intermediate between those selected). On the same sheet were plotted, with duration for abscissa and intensity for ordinate, points representing the rainfalls of the fourteen years at Chestnut Hill, as given in Mr. Dorr's diagram of 1892. If the point representing a rainfall comes below the enveloping curve, it is plain that (had the proposed conduit then been in operation) no overflow from the conduit would have taken place on that occasion; but if above the enveloping curve, the flow would have exceeded the capacity of the conduit, and the excess would have overflowed into the Fens or into the basin. *It is found that, during the fourteen years covered by Mr. Dorr's diagrams, on only sixteen occasions would the rainfall have exceeded the capacity of the proposed conduit. The aggregate duration of rainfall on these sixteen occasions was 17.6 hours*, and the total depth of rain that fell, 22.35 inches. Without tedious calculation, it is impossible to determine closely what proportion of this rainfall would have been carried off by the conduit, and what portion would have overflowed; but a limiting amount can be set, and a brief calculation shows that the total depth of rainfall over and above what the conduit could have accommodated was *not more than* 5.32 inches. Taking into account the fact that on twelve of the sixteen occasions a part only of the 1,430 acres would have contributed to the overflow, and also the fact that not the whole of the rainfall runs off during the storm, it appears that *less than* 3,936 acre-inches of water would have overflowed into the basins in the fourteen years. This is about 20 per cent. of the total amount that would have reached the sewers in the same storms, as calculated by using the same percentage of run-off as in calculating the overflows. It therefore appears that, *of the storm water that reached the sewers on the occasions when the overflows would have occurred, less than 20 per cent. would have overflowed; and therefore less than 20 per cent. of the sewage originating on the 1,430 acres during the 17.6*

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* The excess of rainfall capacity at Hereford Street and below, for short rains, over that at Huntington Avenue, is of course only apparent, and due to the method of calculating. When the same flow that uses the full capacity of the conduit at Huntington Avenue reaches Cambridge Street, it will use the full capacity at Cambridge Street also.

hours of overflow-producing rainfall would have entered the basin. Thus the aggregate discharge of sewage from this district into the Charles in fourteen years would have been equivalent to only 3.5 hours total sewage production, — a truly infinitesimal quantity, — if this district of 1,430 acres had been provided with an intercepting conduit of 700 cubic feet per second capacity. The population of the 1,430 acres in 1900 was about 100,700. The above computation takes no account of the flushing of deposits from the sewers by the strong currents due to the overflow-producing storms, and these flushings are doubtless an important factor in the impurity of the overflow water of sewers, but the overflows of the intercepting conduit would seldom begin until after rain had been falling for some time. This is especially true of the overflows which discharge any considerable volume of water into the basin. On the sixteen occasions in fourteen years above referred to, 82 per cent. of the total volume of overflow would have been due to the ten rainfalls lasting one hour or more. It is true that the more remote parts of the drainage area would generally be contributing their first wash at the time of the beginning of the overflow; but in the lower part of the area, containing the greater part of the population, the sewers would be largely cleared of deposits before the overflows could begin.*

It is thus plain that this proposed marginal conduit of 700 cubic feet per second capacity would provide so fully for carrying off the mingled storm water and sewage of the 1,430 acres that the pollution of the basin due to overflows from the conduit would be so slight as to be harmless, especially as rainfalls so extremely heavy as to overflow the conduit would always cause the flow of the river to increase, and so bring about a partial change in the water of the basin. So far, therefore, as the purity of the basin is concerned, these 1,430 acres may be allowed to remain indefinitely on the combined system, if the marginal conduit plan should be adopted.

Data for computing Sectional Area of a Marginal Conduit of 700 Cubic Feet per Second Carrying Capacity.

The hydraulic gradient available in the proposed conduit will vary with the height of the tide below the dam. When the tide is low, the hydraulic gradient will be very large; when the tide is high, if no pumps are to be provided, there will be no gradient, and the conduit cannot continue to discharge below the dam. When a severe rainfall occurs near the hour of high tide, the storm water must therefore overflow into the basin and for this purpose overflow weirs must be provided at intervals along the course of the conduit. These weirs will come into use also on those rare occasions, about once a year, when the flow from an extraordinary storm exceeds the normal capacity of the conduit. The greatest height allowable for water in the up-stream portion of the marginal conduit depends on the desire to remedy present unsanitary conditions, caused by sewage backing up into cellars when heavy rainfalls now occur at high tide. The mean tide now rises to grade 10.44, city base, and ordinary spring tides to grade 11.24, and in easterly storms tides as high as grade 13.50 are not very uncommon, occurring about once a year. The highest tide known, that of the "Minot's ledge storm," rose to 15.6. While a hydraulic grade limit of 10 feet above city base at the head of the marginal conduit would be an improvement on present conditions, a limit of about 9 feet is preferable. Therefore the crest of these overflow weirs along the conduit should

* A synopsis of the studies relating to the frequency of overflows from the proposed conduit was prepared, but has not been included in the printed report.

not be placed higher than 9 feet above city base unless it should be found on further investigation that a higher elevation can be allowed without risk of flooding.*

The distance from Charlesgate East to the site of the proposed dam is about 10,000 feet; and therefore an average gradient of 1 : 5,000, or not far from 1 foot per mile, for the portion of the conduit below Charlesgate, would give 2 feet fall, and the conduit would carry its full 700 cubic feet without recourse to pumping, at all times when the harbor tide level was below grade 7, and at lower tides would carry much more.

From the gate house in the Fens to the bank of the Charles at Charlesgate East the gradient available is 1 : 2,000.†

Making use of these gradients, designs have been made for a conduit to carry off 700 cubic feet per second. From the old Stony Brook gate house to the river, a distance of about 3,700 feet, the route would be principally through the Fens. A pile foundation would be required, and I estimate the cost at about \$51 per linear foot × 3,700 feet = \$189,000.

From Charlesgate to Cambridge Street, 7,000 feet, the conduit would be under the proposed embankment outside the present sea wall. Piles would be needed, and the cost would be \$56 per foot; total, \$392,000.

From Cambridge to Leverett Street, 2,200 feet, the location would be through the Charlesbank, and the cost would be \$56 per foot, without piles, which, however, might be required for a part of the way, at an estimated cost of \$4,000; total, \$127,000.

The total cost of the conduit from the Charlesgate to below the proposed dam site at Craigie bridge would be \$392,000 + \$127,000 = \$519,000, to which must be added about \$80,000 for gates and connections, and about 10 per cent. for engineering and contingencies, making the total cost of marginal conduit from Fens outlet at Charlesgate to below the dam \$659,000.

The extension within the Fens from Beacon Street to old gate house in replacement of old 7-foot channel would add, as above, \$189,000 + 10 per cent. = \$208,000.

In Moderate Storms the Marginal Conduit can be made to serve Other Territory outside the 1,430 Acres.

Not included in the 1,430 acres reckoned above as tributary to the marginal conduit are the remaining 1,987 acres of Stony Brook territory sewered on the combined system. These, together with a large area sewered on the separate system, are tributary to the Stony Brook

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* It might perhaps even be advisable to provide a number of tide gates opening outwards from the conduit into the basin, immediately above the dam. Through these, when the tide below the dam is above grade 8, the muddy storm water would be discharged into the down-stream end of the basin, instead of being backed up to overflow at the weirs; and the increased flow of the river resulting from the same storm would probably soon take the greater part of it over the dam. If the crest of the overflow weirs along the conduit should be placed at grade 9, the conduit could deliver at these tide gates about 490 cubic feet per second, when the water in the basin was at grade 8 and the harbor tide at a higher grade; and if it should be deemed safe to allow the water level in the up-stream portion of the marginal conduit to approach grade 10, the conduit would have at all stages of the tide its full capacity of 700 cubic feet per second, delivering it below the dam when the harbor tide was below grade 8, and immediately above the dam when the tide was at a higher level.

† This is on the assumption that the old channel is to be rebuilt, enlarged and at a lower grade, from Elmwood Street to the gate house, and that the flood level at Elmwood Street can rise to grade 14 without damage.

valley sewer, which enters the main drainage system at Elmwood Street, where it has also a storm outlet into the "old channel" of Stony Brook. The Stony Brook valley sewer is far too small to carry off the storm water of the area that it serves, and so numerous lateral overflows tributary to the new channel of Stony Brook have been provided.

In their present overtaxed state, the main drainage works can carry off but little, in time of storm, of the sewage of the Stony Brook valley sewer. The "old channel" is so small and at so high a grade that it becomes gorged by the storm water necessarily tributary to it, so that the overflow outlet at Elmwood Street is practically inoperative. Consequently, in time of storm, nearly the whole discharge of the Stony Brook valley sewer — sewage, street wash and flushings — goes into the new channel of Stony Brook, and reaches the pond in the Fens, to the impurity of which it contributes materially, and through which it enters the Charles.

To do away with this sewage pollution by the complete introduction of the separate system of sewerage would cost about $1,698,000, and would not divert the street wash from the Fens or from the basin. Furthermore, even if the money were immediately available, to carry out the work would take a long time. Can the need of this expenditure be postponed in any way?

1. The operation of the high-level sewer will diminish the amount and the foulness of the overflows into the new channel of Stony Brook, both directly, by diverting a portion of the sewage, and indirectly, by relieving the Boston main drainage works, and so enabling them to carry off more of the storm water of the Stony Brook region.

2. The much-needed rebuilding of the "old channel," enlarged and at a lower grade, will do away with the gorging at Elmwood Street, and will enable the rebuilt "old channel" to take a considerable proportion of the storm overflow of the Stony Brook valley sewer, thus greatly enlarging the area tributary in time of storm to the marginal conduit.

3. The 12-foot channel proposed by the sewer division, at a cost of $300,000, from the mouth of the present "new channel" of Stony Brook in the Fens to the Charles, or the much less expensive substitute conduit proposed by the city engineer, from the mouth of the "new channel" to the gate house in the Fens, if constructed in connection with the marginal conduit, would divert from the Fens and from the basin not only the ordinary flow of Stony Brook, but also the sewage overflow and street wash due to thaws and moderate rains. If, ultimately, it should be found necessary to adopt the separate system, either of these works would still be useful to divert the street wash.

Brookline.

The sewers of Brookline are partly on the combined system, and have an overflow outlet at St. Mary's Street,* where there is also an overflow outlet from the metropolitan sewer. An extension of the intercepting conduit, about 4,100 feet long and of comparatively small diameter, would intercept the discharge from these overflows in moderate storms. In case the "12-foot conduit" should be constructed, the regulators should be so arranged as to give the preference to the discharge from St. Mary's Street whenever both could not be accommodated; for the discharge from the 12-foot conduit would probably

* The Brookline sewers have another overflow debouching into Muddy River near Aspinwall Avenue.

be less foul, and more suitable to be turned into the basin. A conduit 5 feet in diameter, from St. Mary's Street to Charlesgate East, by way of Commonwealth Avenue or Bay State Road and Beacon Street, would cost about $100,000 (a rough estimate).

Area not Tributary to the Marginal Conduit.

In the part of Roxbury and West Roxbury tributary to the Brookline sewers, the separate system is already partly introduced. Here and in the Back Bay west of the Fens the separate system is the most suitable means of diverting sewage from the basin. The cost will be about $230,000, of which $176,000 is for street pipes, etc., and $54,000 for changing house connections. All the sewage will go to the high-level sewer.

Brighton is sewered partly on the separate system, but chiefly on the combined system. All its sewers will be tributary to the high-level sewer, and it is probable that the separate system will be adopted eventually for all of them. The cost, if the change should be made now, would be about $580,000 for street conduits and about $193,000 for house connections and plumbing; total cost, $773,000, which does not include the cost of enlarged channels for the principal water courses, necessary in any case to prevent flooding. The change to the separate system may not be completed for a number of years. In the mean time, the frequency of overflows can be diminished at a moderate cost by excluding the water of brooks and springs wherever they have been allowed to enter the sewers.

The metropolitan sewer, which receives the sewage of Brighton, carries also the sewage of Newton, Watertown and Waltham, which are sewered on the separate system. Until Brighton is provided with a separate system, the regulators on the Brighton sewers ought to be so adjusted as to reject the combined Brighton sewage and storm water whenever it would overcharge the metropolitan sewer, reserving the capacity of the latter at such times for the undiluted sewage of Newton, Watertown and Waltham.

To make the separate system effective, and to reduce the cost of its introduction, changes in the plumbing law are required, applicable to districts where the separate system has been introduced, and to districts where it is planned in future to introduce it. In the former it should be unlawful to connect roof-water pipes directly or indirectly with the sewer, and in the latter the connection of roof-water pipes with the interior plumbing of buildings should be prohibited.

Mr. Cutter's report contained many interesting studies, computations in detail, which we have not room to introduce. A complete copy is to be placed on file in the city engineer's office, Boston.

Appendix No. 16.

Measurement of Flow of Upland Water into Charles Basin.

Report by John R. Freeman, C.E.
Field work chiefly by R. A. Hale, C.E., and W. E. Spear, C.E.

Whether or not the sewage entering the basin will be diluted sufficiently to become inoffensive depends largely on how much fresh water comes into the basin to dilute it.

In the studies by the Joint Board of 1894, and in the reports of the engineering experts presented at the hearings of 1902, the flow of the Charles River was estimated by analogy from the measured flow of the Sudbury River as recorded for many years past by the Boston water works. This estimate was based on the assumptions: —

(1) That one-third of the flow from the drainage area of the Charles above Dedham was diverted into Mother Brook, leaving, after allowing for sundry other diversions, 204 square miles net drainage area.*

(2) That the yield per square mile of the drainage area of the Charles was precisely the same as that of the Sudbury for every month in the year.

In the report of the Joint Board of 1894, their chief engineer, Mr. F. P. Stearns, stated (p. 2) that the ordinary summer flow "could be reckoned at 62 cubic feet per second, and the minimum flow is not more than half this amount."

In the evidence of 1892, p. 113, Mr. Goodnough estimated that the mean flow in the severe drought of 1900 averaged 59.9 cubic feet per second, for the three months, July, August and September.

Mr. Percy M. Blake (evidence, p. 196) reckons the proportionate flow of the Charles in the great drought of 1883, for July, at 39 cubic feet per second; for August, at 26 cubic feet per second; for September, at 31 cubic feet per second. This drought of 1883 was probably the most severe of any for more than half a century past.

It appeared to me that this question of the amount of fresh upland water available in months of extreme drought for diluting the sewage entering the Charles basin was of too great importance in the present problem to be left resting solely on this assumed analogy to the Sudbury and the assumption that exactly one-third was diverted into Mother Brook, for it appeared that there was a possibility that a serious interference with the uniformity of the flow might be caused by the irregular

* Blake, evidence, p. 197, reckons this at 217 square miles. Stearns, report of 1894, calls it 204 square miles. There is also some drainage area contributing clean water below the Watertown dam.

use of the water power by the Boston Manufacturing Company, which controls the outlet of the large pond formed between Newton Lower Falls and Waltham.

On visiting the Boston Manufacturing Company's works, I was very kindly given access to its water power records; and soon found that there had been many periods, during severe droughts, in which the water wheels had been shut down completely for days or weeks at a time. It also appeared from these records that during these periods of shut-down the rate of rise of water in the mill pond was not large, and this in turn indicated a low rate of river flow.

The rainfall in the months immediately preceding our first study of this question, in August, 1902, had not been large, and the river flow at this time appeared small; and it appeared wise to undertake a careful continuous gauging of the quantity of water entering the basin, although it was hardly probable that anything that could properly be called a severe drought would occur during the next month or two, and notwithstanding the fact that the preparations for this gauging would involve a considerable expense. Some sheet piling had to be driven, flashboards set and weirs constructed, and so the measurements were not fairly started until late in September.

Gauging of River Flow at Watertown Dam.

The daily flow of the Charles River at the Watertown dam was gauged continuously for two and one-third months, or from September 26, until interrupted by the freezing weather following Dec. 5, 1902.

To determine the total quantity of water passing, it was necessary to measure: —

(1) The discharge over the dam.

(2) The wash water used by the Union Bag and Paper Company.

(3) The flow through the canal leading to the old grist mill and foundry, which is made up of leakage at the disused turbines at these mill sites, and of the wash water drawn by Lewando's dye and cleansing works.

The water rights of the Watertown dam are owned by: —

(*a*) The Union Bag and Paper Company, which draws directly from the pond.

(*b*) The grist mill property, now owned by the Waltham Savings Bank.

(*c*) The old foundry property, now in possession of the Metropolitan Park Commission.

(*d*) Water for washing and dyeing is also drawn from above the fall by Lewando's dye and cleansing works; but, so far as we were able to learn, the Lewando establishment owns no very definite water rights.

There are no water wheels now in use at any of these mill sites. Nothing is now drawn for power or other use at the grist mill site or at the foundry site; and the paper company long since discontinued the use of turbines, and now draws nothing but wash water. The amount of wash water drawn by the Lewando works is comparatively small.

The flow of the river has to be measured in three parts, it being made up of: —

(1) The flow over the dam.

(2) Wash water of Union Bag and Paper Company.

(3) Flow through canal, which supplies the small quantity of wash water used by the Lewando dye works, and the leakage at the old grist mill and foundry sites.

(1) *Measurement of Flow over the Dam.* — The Watertown dam is a wooden structure, built in recent years, and is in good condition. It was examined for leaks at low tide, and none of importance found, except that about 0.5 cubic foot per second was found leaking through the nine sluice gates, and for this due allowance was made.

The total length of this crest is about 175 feet. In order to increase the precision of measurement of the quantity flowing over this crest, we had flashboards about 1 foot in height placed upon the crest of this dam, so as to cover its entire length excepting a gap of 40 feet near the north end, where the crest was very nearly level. These flashboards were made tight by dusting, and served to turn the entire flow into this space 40 feet in width, and thus gave a sufficient depth to enable the discharge to be measured with accuracy.

Planks were put on above each of the nine waste gates at the north end of the dam, to such a height that no ordinary flow of water would pass over them.

In selecting formulas for computing the flow over the dam, its cross-section was compared with the sections of sundry other dams of which the rate of flow for different depths had been accurately measured, and a diagram for its discharge at different depths was prepared, based mainly upon one of the Cornell experiments for a crest intermediate in form between the Croton and the Lawrence dams.

Later in the season, after the fall rains, the larger flow which came over the top of the flashboards and over the top of the waste gates was computed by the Francis formula for a sharp-crested weir. The tops of these flashboards were not cut to the same level with such accuracy as would have been secured had we anticipated measuring flow over them, but each was levelled on carefully, and thus a fair degree of precision of water measurement over them was secured.

Measurement of Depth. — The depth of water flowing over the dam varies widely at different hours of the day, by reason of the irregular discharge from the factories farther up the stream. A clock gauge was therefore set near one end of the dam, at a point convenient for accurately giving the depth over the dam, and also for the depth on a weir that we had placed in the old canal at the same height as the crest of the dam.

The clock gauge was adapted for a week's run, but in order to lessen the chance of error, it was visited daily by one of our assistant engineers; and the curve automatically drawn on its chart was verified daily by comparison with a graduated scale that had been set by a levelling instrument, so as to show the depth on the dam. Its operation and precision of measurement were very satisfactory.

(2) *Measurement of Wash Water at Union Bag and Paper Company.*

(*a*) Raceway: Most of the wash water used in the paper mill is discharged into the raceway that flows out below the mill. To measure this we had a line of sheet piling driven across the canal. In the centre of this piling a space about 10 feet in width was cut out, and the water made to discharge over a sharp-crested weir having no end contractions, located in this gap. A weir scale was read twice each day by Michael Hanrock, an employee of the paper mill, and these readings were confirmed by at least one observation daily by the assistant engineer who cared for the recording gauge.

High tide submerges this weir for an interval of about an hour, but does not check the flow of wash water from the paper mill; thus the quantity passing over the weir, amounting to about 6 feet per second,

is fairly constant, and therefore the submergence does not interfere with the accuracy of measurement. This piling and the weir were carefully made tight by dusting.

(*b*) Twenty-four-inch pipe line: The remainder of the paper mill wash water passes out through a 24-inch pipe. A box was placed over the end of this pipe and tightly caulked, and a 3-foot weir constructed in the end of the box. The quantity passing over this weir was regularly found to be very small, less than 1 cubic foot per second, and very nearly uniform.

(3) *Flow through Canal.* — The flow through the canal is made up, as before stated, of the leakage at the old mill sites and the water used by the Lewando dye works. The volume flowing into this canal was determined by a sharp-crested weir placed in the canal opposite the office of the paper company, where an old line of sheet piling existed, and, as already stated, this weir crest was placed as nearly at the same level with the crest of the dam as was practicable.

To avoid cutting off Lewando's water supply during these tests, the crest of this weir across head of old canal had to be placed about as low as the crest of the main dam, and when the water reached a height corresponding to 0.7 or 0.8 above the dam, this forced more water over this weir and into the canal than the leakage and draft could take away; the water then rose in the canal so as to submerge the weir. To avoid this submergence of the weir the leakage from the canal was increased by opening a gate at the foundry site. This expedient served to keep the canal drawn down sufficiently so that there was always a free supply of air under the sheet of water passing over the weir at all depths.

Method of Computation. — The clock gauge charts were subdivided into sundry intervals of nearly constant depths and from the average depth during each interval the flow was computed by means of the diagram already described. The float and levers connected with the clock gauge were adjusted with much care, to avoid friction; and the agreement between the depths shown by the line on the chart and that shown by the daily hook gauge reading and a daily scale reading were very satisfactory throughout the whole period of measuring. It is therefore believed that the quantities given in the following table are thoroughly reliable. Perhaps, notwithstanding the apparent tightness of the dam, there is some percolation through the porous earth in vicinity of dam; but this appears hardly noteworthy when we consider the effect of any such filtering action upon filling and clogging the minute channels and pores during the past one hundred years while a dam has existed here. The chief cause of uncertainty is the possible error in the formula used for computing the discharge over the dam; and, after reviewing all possible sources of error, it appears that the margin of uncertainty in the following measurements can hardly exceed 5 per cent., and is as likely to be in one direction as in the other.

Table showing Daily Flow of the Charles River at Watertown from Sept. 26 to Dec. 5, 1902.

DATE. 1902.	DAY OF THE WEEK.	Average Flow of River at Watertown Dam (in Cubic Feet per Second per Twenty-four Hours).	DATE. 1902.	DAY OF THE WEEK.	Average Flow of River at Watertown Dam (in Cubic Feet per Second per Twenty-four Hours).
Sept. 26,	Friday,	39.4	Nov. 1,	Saturday,	112.3
27,	Saturday,	30.1	2,	Sunday,	21.7
28,	Sunday,	11.3	3,	Monday,	149.6
29,	Monday,	44.9	4,	Tuesday,	153.8
30,	Tuesday,	36.9	5,	Wednesday,	152.5
Oct. 1,	Wednesday,	69.9	6,	Thursday,	154.2
2,	Thursday,	69.0	7,	Friday,	153.6
3,	Friday,	69.1	8,	Saturday,	102.1
4,	Saturday,	79.9	9,	Sunday,	20.4
5,	Sunday,	23.5	10,	Monday,	132.6
6,	Monday,	68.8	11,	Tuesday,	161.6
7,	Tuesday,	82.5	12,	Wednesday,	151.0
8,	Wednesday,	83.3	13,	Thursday,	153.7
9,	Thursday,	85.7	14,	Friday,	145.4
10,	Friday,	87.1	15,	Saturday,	59.8
11,	Saturday,	61.7	16,	Sunday,	15.8
12,	Sunday,	14.5	17,	Monday,	65.1
13,	Monday,	79.5	18,	Tuesday,	75.5
14,	Tuesday,	97.7	19,	Wednesday,	82.6
15,	Wednesday,	98.9	20,	Thursday,	80.7
16,	Thursday,	126.3	21,	Friday,	82.3
17,	Friday,	144.5	22,	Saturday,	67.1
18,	Saturday,	105.2	23,	Sunday,	33.9
19,	Sunday,	61.6	24,	Monday,	84.0
20,	Monday,	139.2	25,	Tuesday,	80.0
21,	Tuesday,	119.0	26,	Wednesday,	91.5
22,	Wednesday,	69.4	27,	Thursday,	43.1
23,	Thursday,	67.4	28,	Friday,	105.7
24,	Friday,	68.7	29,	Saturday,	76.5
25,	Saturday,	51.9	30,	Sunday,	42.8
26,	Sunday,	16.3	Dec. 1,	Monday,	118.4
27,	Monday,	69.1	2,	Tuesday,	121.2
28,	Tuesday,	111.0	3,	Wednesday,	138.4
29,	Wednesday,	108.7	4,	Thursday,	141.1
30,	Thursday,	135.2	5,	Friday,	141.4
31,	Friday,	148.0			

It will be noted that the average of the first five days is only 32.5 cubic feet per second. This marked the close of the most severe drought of the present summer, but this was not nearly so severe a drought as that of the year 1900, or various other years.

CONCERNING THE PROBABLE MINIMUM FLOW OF CHARLES RIVER.

As already stated, an examination of the power records of the Boston Manufacturing Company showed that there had been times when the flow of the river was very much less than at any time during the past summer, and an examination of these power records during the recent severe drought of 1900 indicated a smaller flow than that estimated by Mr. X. H. Goodnough. (Evidence, p. 113.)

Mr. Goodnough's estimate of the flow of the Charles during this period had been based in part upon analogy of the flow of the Sudbury River and in part from the daily record of the depth measured at a gauging station maintained by the State Board of Health somewhat more than half a mile above the silk mill at Newton Upper Falls.

On attempting to study into this matter with more detail, some very puzzling discrepancies were found between the quantity flowing as deduced from the water power records of the Waltham mills and the quantity deduced from the depths observed daily at the State Board of Health gauging station a few miles up stream; and, notwithstanding the attention subsequently given, I have been unable to reconcile these estimates. This discrepancy is further discussed on page 465. The pressure of other work did not leave me time to investigate this matter properly, and I therefore asked Mr. Richard A. Hale, principal assistant engineer of the Water Power Company, whose twenty-five years' experience with the daily water measurements at Lawrence has made him exceptionally expert in all matters of this kind, to study into the matter of these water power records with all possible thoroughness. His report follows: —

REPORT OF R. A. HALE, C.E., ON FLOW OF CHARLES IN EXTREME DROUGHT, AS INDICATED BY WATER POWER RECORDS OF BOSTON MANUFACTURING COMPANY, WALTHAM.

LAWRENCE, MASS., NOV. 21, 1902.

JOHN R. FREEMAN, Esq., *Chief Engineer, Committee on Charles River Dam.*

DEAR SIR: — I herewith present tables and report in regard to the flow of the Charles River at dry-weather periods from 1877 to the present time, and during the last four years a statement of the average weekly flow for the six dry months of each year. The point at which flow is estimated is at the Boston Manufacturing Company's dam at Waltham, where records have been kept in regard to the height of the water and the estimated horse-power used by the wheels since 1877; and their data have been used in making these estimates, together with what other facts were available in reference to conditions of the flow. The records kept at the Boston Manufacturing Company showed the height of water with reference to the crest of the dam and the estimated horse-power used by the wheels. From 1877 to April, 1902, there have been six water wheels in use, three 72-inch Swain and three 48-inch Boydens. Since April, 1902, the three Boyden wheels have been out of use, and have been replaced by new Hercules wheels.

From the estimated power of the Swain and Boyden wheels the quantity of water has been estimated and the flow determined by working backwards from the power shown in the records. The data in regard to the wheels had been previously obtained from the builders in connection with suits in progress between Cambridge, Waltham and the Boston Manufacturing Company. The subject of dry-weather flow was of special interest, as it appears from the records that for a period of twenty-five years the wheels were all closed for a period varying from a week to three months each year, the latter amount occurring in 1894, and this for an almost incredible period for a drainage area of this size of 162 square miles. No record was kept in regard to the condition of the wheels and leakage, but it was stated by Mr. Jones, master mechanic of the Boston Manufacturing Company, that the Swain wheel gates were quite tight, and there was considerable leak about the Boyden wheels, but the quantity had not been measured or estimated.

The Waltham bleachery, formerly connected with and a part of the Boston Manufacturing Company, is located on the Charles, about a half mile below the dam of the manufacturing company, and takes its supply of water for bleachery purposes from the river by a dam 5 feet in height across the river, through a canal about 10 feet in width and 3 feet in depth. This canal extends through the yard and under the buildings, where the water is used for bleaching, rinsing, etc., and discharges over stop-plank at the end of the mill. No water wheels are used at this site, and the surplus water that is not used in the bleachery wastes over the dam. As the water used at the bleachery depended on the amount passing the Boston Manufacturing Company's dam and wheels, during dry periods an examination of this quantity drawn and data relating to the same were made.

In the suit of the Boston Manufacturing Company *v.* the city of Waltham, in 1900, relating to damages due the diversion of 2,000,000 gallons of water from the Charles River, Mr. Getchell, the superintendent of the bleachery, stated that *there were dry periods every year when the entire flow of the Charles River was used at the bleachery.* He made measurements of the water in the canal

by using floats and taking the sections, and found that in the ordinary running the bleachery used 3,000,000 gallons per day during the ten hours, or 10.5 cubic feet per second during that period. He said that *at times it might fall below that, as he was obliged to send up word to the Boston Manufacturing Company to open their wheel gates slightly or to remove a flashboard from one bay of the dam in order to supply this amount to the bleachery.*

The amount leaking from the wheels, together with the water used for washing and dye house, was not sufficient at all times for their supply. Mr. Getchell also stated that *the top of the dam as the bleachery was usually dry during these dry periods; and the leakage from the wheels which existed during the twenty-four hours was stored in the pond, so that it did not waste over the bleachery dam;* that on some mornings it was just "slopping over, but not wasting." In a recent interview with him he corroborated the statements he made in the case, and was very confident that there was *none wasting over the dam during those dry periods.*

To verify the quantity used at the bleachery, two measurements were made with floats in a uniform section of the canal at the bleachery on Nov. 17, 1902, and the quantity passing was 9.7 cubic feet per second and 10.2 cubic feet per second, or a mean of 10 cubic feet, agreeing with Mr. Getchell's statement. The amount of work, rinsers, etc., and general conditions are the same as in 1900. It would appear that during the dry period 10 cubic feet per second for ten and a half hours, or 4.4 cubic feet for twenty-four hours, was the amount that could be drawn by the bleachery.

At the Boston Manufacturing Company an estimate is made by them that 2,000,000 gallons per day, or an equivalent of 3 cubic feet per second for twenty-four hours, is used for washing, dye house, etc. Mr. Jones, master mechanic for the Boston Manufacturing Company for many years, considers that the Swain wheels, 1, 2, 3, close very tight, and that the three Boyden wheels leaked considerably. The Boyden wheels were entirely shut off in April, 1902, and for four years previous to that time had been gradually silting up with mud, etc., in consequence of not being used, and therefore reducing the leakage.

In the estimates of the flow I have allowed 3 cubic feet per second during twenty-four hours as water for washing, dye house, etc., at the mill; and previous to 1898 allow 1 cubic foot per second to each wheel for leakage, in addition to the use at the mill, making *a total of 9 cubic feet per second for twenty-four hours. This is somewhat larger than Mr. Getchell testified to, but would allow for some wastage* if the gate to the bleachery canal was not always closed at night.

The tables show the average twenty-four hour flow in cubic feet per second by weeks, taking intervals of dry periods in each year, and showing the number of weeks that this period existed, and the cubic feet per second per square mile yield. The maximum and minimum weekly flow of each period is also given. The driest period of greatest length was in 1894, when for nearly three months no wheels were run. The water in the pond above the dam was drawn down about 2 feet at the beginning of the period, and whatever flow existed was used in filling the pond, which did not reach its height at which wheels were started for three months. The water used at bleachery was leakage from the wheels, and a wheel gate hoisted at intervals when needed.

During these dry periods Beaver Brook supplied no visible water from its drainage area. The second table shows the average flow in cubic feet per second for the driest six months, from 1898 to 1902, obtained from the Boston Manufacturing Company's records. As a check on the flow from the Boston Manufacturing Company's records, a comparison was made, taking a few days in October, of your recent weir measurements at Watertown with the Boston Manufacturing Company's records, and correcting for drainage area. The Boston Manufacturing Company's records indicate 67 cubic feet per second for twenty-four hours, while the actual measurements at Watertown were 65 cubic feet per second for twenty-four hours. With a larger quantity the mean of several days showed the Boston Manufacturing Company's records as 117 cubic feet for twenty-four hours, and Watertown weir measurement as 123 cubic feet per second. From their general methods of keeping the records, the comparisons show a close agreement.

Very respectfully yours,

R. A. HALE, *Civil Engineer.*

Estimated Flow of the Charles River at the Boston Manufacturing Company's Dam at Waltham, Mass., during Dry Periods, from 1877 to 1898. (By R. A. Hale, C.E.)

Year.	Duration of Drought, Number of Weeks in Each Year.	Weekly Average Flow for Twenty-four Hours during Drought. Cubic Feet per Second.	Weekly Average Flow for Twenty-four Hours during Drought. Cubic Feet per Second per Square Mile. 162 Square Miles.	Weekly Minimum Flow during Drought (Cubic Feet per Second).	Weekly Maximum Flow during Drought (Cubic Feet per Second).
1877, . . .	4	46	.28	32	54
1878, . . .	4	31	.19	28	36
1879, . . .	8	35	.21	35	35
1880, . . .	25	30	.18	30	30
1881, . . .	4	30	.18	18	31
1882, . . .	9	26	.16	11	35
1883, . . .	18	24	.15	19	39
1884, . . .	9	20	.12	9	33
1885, . . .	9	27	.17	21	33
1886, . . .	9	20	.12	15	32
1887, . . .	8	40	.24	29	44
1888, . . .	7	34	.21	28	48
1889, . . .	3	51	.31	48	53
1890, . . .	10	35	.21	27	46
1891, . . .	8	39	.24	39	39
1892, . . .	10	34	.21	23	48
1893, . . .	13	26	.16	19	38
1894, . . .	17	17	.10	9	53
1895, . . .	17	27	.17	11	44
1896, . . .	9	26	.16	9	44
1897, . . .	7	24	.15	22	37
1898, . . .	3	46	.28	33	67

Note by J. R. F. — The above not to be relied on as conclusive, because of uncertain leakage and some indefiniteness as to opening of wheel gate.

Estimated Flow of the Charles River at the Boston Manufacturing Company's Dam at Waltham, Mass., deduced from the Boston Manufacturing Company's Records. (By R. A. HALE, C.E.)

1899.		1900.		1901.		1902.	
WEEK ENDING —	Quantity passing (Cubic Feet per Second for 24 Hours).	WEEK ENDING —	Quantity passing (Cubic Feet per Second for 24 Hours).	WEEK ENDING —	Quantity passing (Cubic Feet per Second for 24 Hours).	WEEK ENDING —	Quantity passing (Cubic Feet per Second for 24 Hours).
June 4,	41	June 3,	89	July 7,	93	May 4,	89
11,	46	10,	132	14,	51	11,	86
18,	26	17,	132	21,	94	18,	83
25,	17	24,	112	28,	94	25,	86
July 2,	15	July 1,	105	Aug. 4,	131	June 8,	69
9,	20	8,	49	11,	94	15,	38
16,	12	15,	24	18,	74	22,	34
23,	17	22,	7	25,	94	29,	38
30,	15	29,	6	Sept. 1,	112	July 13,	30
Aug. 6,	13	Aug. 5,	6	8,	100	20,	30
13,	24	12,	6	15,	94	27,	30
20,	19	19,	6	22,	89	Aug. 3,	28
27,	7	26,	42	29,	85	10,	20
Sept. 3,	7	Sept. 2,	24	Oct. 6,	94	17,	21
10,	7	9,	6	13,	94	24,	20
17,	7	16,	6	20,	90	31,	20
24,	10	23,	27	27,	94	Sept. 7,	17
Oct. 1,	40	30,	38	Nov. 3,	90	14,	20
8,	15	Oct. 7,	11	10,	94	21,	20
15,	44	14,	43	17,	94	28,	20
22,	28	21,	78	24,	86	Oct. 5,	28
29,	19	28,	51	Dec. 1,	79	12,	28
Dec. 3,	37	Nov. 4,	52	8,	96	19,	70
10,	19	11,	85	15,	108	26,	66
17,	28	18,	78	22,	116	Nov. 2,	92
24,	28	25,	85	29,	110		
Jan. 1,	34	Dec. 2,	148				

NOTE by J. R. F. — Above not to be relied on as conclusive, because of uncertain leakage.

A comparison of certain of the above estimates based on the power records at Waltham, with the flow measured at Watertown, given on p. 459, presents the following important differences: —

WEEK.	Waltham Power Records.	Watertown Gauging.	Excess by Gauging.
September 22–28,	20	32.0(?)	12
September 29–October 5,	28	56.2	28
October 6–12,	28	69.0	41
October 13–19,	70	93.0	23
October 20–26,	66	75.0	9
October 27–November 2,	92	101.0	9

These large differences show that the estimates of flow in moderate droughts, based on the power records alone, are to be used with caution.

Concerning Reliability of the Power Record Estimates of Flow. — It will be noted, on examination of Mr. Hale's report, given above, that several occasions appear, on which the flow was surprisingly small for several weeks at a time. For example, in the great drought of 1880, these records would indicate that for twenty-five weeks continuously the flow averaged only 24 cubic feet per second; and that in the great drought of 1883 the flow for eighteen weeks continuously averaged only

24 cubic feet per second. Similarly, in 1894, the water power records would indicate seventeen weeks in which the flow averaged only 17 cubic feet per second; and in the year 1900, from July 17 to August 20, a period of five weeks, the turbines were entirely shut down, and the flow past the dam apparently averaged only about 6 cubic feet per second. *All of these estimates based on the water power records are, however, open to some uncertainty about the quantity of water leaking through the turbines while their gates were shut*; but all of the evidence that can be obtained from careful inquiry at the mill tends to support the figures just quoted.

Nevertheless, this volume, averaging only 6 cubic feet per second for five weeks continuously in 1890, is incredibly small for a stream of so large a drainage area, and is much smaller than an estimate of the flow of the Charles River at Newton Upper Falls made during the same period, based on two observations daily of the height of water in a portion of the river where the channel is uniform, located about one mile up stream from the silk mill.

Comparison of Sundry Gaugings and Estimates of Flow of Charles River during the Drought of 1900 (Cubic Feet per Second).

WEEK ENDING SUNDAY.	AT NEWTON UPPER FALLS.		Probable Diversion for Public Water Supply, Wellesley and Waltham.	River Flow gained or lost, due Visible Fall or Rise in Waltham Mill Pond.†	Flow estimated from Power Records of Boston Manufacturing Company, Waltham.
	At State Board of Health Gauging Station.	At Silk Mill, in Early Morning.*			
1	2	3	4	5	6
July 8,	85	48	4	+ 6 (draft)	49
15,	63	30	4	+ 8 "	24
22,	55	21	4	— 0	7
29,	63	25	4	— 2 (storage)	6
Aug. 5,	66	33	4	— 3 "	6
12,	51	23	4	— 5 "	6
19,	50	29	4	—25 "	6
26,	42	30	4	— 4 "	42
Sept. 2,	22	11	4	+11 (draft)	24
9,	17	10	4	— 4 "	6
16,	14	9	4	+13 (storage)	6
23,	41	30	4	—16 (draft)	27
30,	37	30	4	+11 (storage)	38
Oct. 7,	28	22	4	—12 (draft)	11
14,	58	47	4	—11 "	43
21,	74	63	4	+ 9 (storage)	78
28,	45	42	4	+ 2 "	51
Nov. 4,	56	45	4	–	52
11,	61	42	4	–	85
18,	53	46	4	–	78
25,	54	48	4	–	85
30,	200	171	4	–	148
Driest 5 weeks, July 22 to August 19,	57	26	4	— 9 (storage)	6

* This silk mill gauging is based on depth found flowing over their dam early in the morning, before their mill starts.

† The actual mean rate of flow held back in storage by rise in pond may be 50 per cent. more and perhaps double this, because of storage in porous gravel margins of pond. The quantities in first two columns would be expected to be alike. The quantities in sixth column would naturally be less, because of 4 cubic feet abstracted below Newton Upper Falls and above Waltham for public water supply; also because of evaporation which might perhaps be from 2 to 3 cubic feet per second; also because of the water stored in mill pond while turbines are closed; wherefore, if columns 1 and 2 gave 30 cubic feet per second, we should expect an outflow at Waltham of about 20 to 23 cubic feet per second, if pond did not rise.

Gaugings of Flow of the Charles at Newton Upper Falls. — The estimate of quantity at this point forms a part of the regular stream flow records of the State Board of Health, and the daily estimate is based upon a curve of flow corresponding to different depths, which curve was constructed from a series of current meter measurements. The use of diagrams of this kind may be attended with serious error if there happen to be local circumstances that modify the rate of surface slope; and at this particular point there is good reason to suspect interference from the variable height of water in the mill pond of the silk factory, lying almost immediately down stream from this State Board of Health gauging station; for the height of this pond varies according to the draft for power, irrespective of the rate of flow into the same. Moreover, certain current meter measurements by Prof. Dwight Porter are reported to have shown that at this gauging station of the Board of Health the relation between the depth and the quantity flowing is not constant. I consider that the accuracy of these gaugings is open to serious doubt.

The season had so far advanced by the time that these discrepancies were appreciated, that it was impracticable to thoroughly investigate this gauging station at Newton Upper Falls. Mr. Hale was, however, instructed to go over the ground again and carefully review all of his estimates based on the water power records, and did so, without finding good grounds for modifying the results given in the preceding pages.

At the Waltham bleachery, one-half mile below the Boston Manufacturing Company's dam, Mr. Getchell, the former superintendent, was positive in regard to the conditions previously reported. He had measured the quantity of water by means of surface floats, and found it about 11 cubic feet per second. His recollection was clear that in order to obtain this quantity they had to send up to the cotton mill to ask them to open their wheel gates or take off the flashboards. He was also certain that no water flowed past the bleachery dam at night, and certain that the bleachery gates were substantially free from leakage. The fact that the bleachery requires only about 10 to 12 cubic feet per second during working hours appears fully established. This flow is shut off at night, and therefore the twenty-four-hour rate of flow would be less than half the rate in working hours plus a little night leakage.

At the Boston Manufacturing Company, Mr. Jones, master mechanic, was very confident that nothing unusual in regard to the running of the mill occurred during the dry period of 1900, and was clear in his recollection that during July and August of that year they were obliged to send down water for the operation of the bleachery, sometimes by means of slightly hoisting a gate, or sometimes by taking off a flashboard; and he was also certain that, when the wheels were not operated for a long period at a time, the head gates were closed, and dusted so tight that no water passed.

At the Ætna mills, Watertown, the master mechanic, Mr. Mayo, had no record regarding the flow or the operation of the turbines during the drought of 1900; but his recollection was clear that the water was so low during a portion of July and August that the turbines could not be operated.

At the Union Bag and Paper Company, Mr. Daly has a distinct recollection about the condition of the water during the whole of July and August and much of September, and says that during the early part of July he was obliged to make a cofferdam to hold back sufficient water to supply the paper mill with its wash water of about 7 cubic feet per second (twenty-four hours), and that there was no water flowing to waste for a period of several weeks at a time, particularly during July and August.

Between this gauging station at Newton Upper Falls and the dam of the Boston Manufacturing Company considerable quantities of water are abstracted for public water supply; and, although this is taken from the ground adjacent to the river, it probably affects the river flow to substantially the full extent of the diversion. The diversion for Wellesley probably equals one cubic foot per second, and at Waltham 4 cubic feet per second; and an average allowance for evaporation over this large mill pond would be not far from 3 cubic feet per second, making a total of 8 cubic feet per second probable loss between the gauging station of the State Board of Health and the Waltham dam. Some of the worst of the factory wash water taken from the river may be discharged into the Charles River valley metropolitan sewer. Although the rise in the Waltham mill pond is not large enough to account for the remaining difference, it must be remembered that the margins are probably of porous gravel, in which the ground water rises for a considerable distance back, to correspond with the rise within the open pond. But, after allowing for all of these sources of difference, a considerable discrepancy remains, and the flow into the pond as measured appears too large, or the flow out as found from the power records too small.

Nevertheless, the result of the investigations is valuable, in showing that in extreme drought, *sometimes for from one to two months at a time, the flow is reduced to a point barely sufficient to supply the Boston Manufacturing Company with water for its dye house, the Waltham bleachery with water for wash-water purposes, and barely sufficient to supply the paper mill also for wash-water purposes.* Therefore, it is plain that the water which comes in to the Charles River basin at such times necessarily carries a good deal of pollution, and *cannot in extreme drought prove of full ordinary value per cubic foot for diluting the sewage that enters the basin.*

In approximating to the number of cubic feet per second that this flow amounts to during the one or two months of most extreme drought, I have been led to conclude that, on the one hand, the estimate derived from the water power records is probably too small, because of some uncertainties about the leakage; and that, on the other hand, the estimates based on the daily heights at the gauging station of the Board of Health at the bridge at Newton Upper Falls, about one mile above the silk mill dam, may be affected by the variable height in the silk mill pond, and thus lead to too large an estimate of quantity; and that when, as is unquestionably a fact, the Boston Manufacturing Company shuts down its turbines entirely for a month or more at a time, the capacity for holding back storage in its pond may be augmented by the raising of the water table in the margins of the pond.

Under the present circumstances, and in view of a possible increase in the diversion for water supply purposes in future, I do not think that it is prudent to rely upon an inflow of upland water to the proposed basin greater than somewhere between 10 and 20 cubic feet per second, as an average for the two consecutive months of most extreme drought; and it is certain that under present conditions this water would be fouled by dye stuffs and paper mill washings.

FLOOD DISCHARGE OF CHARLES RIVER.

These investigations were made partly because I noticed the remarkably low wing walls and remarkably small provision for freshets at the mill sites probably a hundred years in use, and therefore presumably found ample, and these indicated a stream of uncommonly small floods; and partly because of the suggestions in Professor Porter's evidence, p. 405, and Mr. Hering's evidence, p. 446, and their quotation of Mr. Alexis French's opinion in 1894, to the effect that 10,000 cubic feet per second would not be an excessive estimate of freshet flow. Mr. Porter and Mr. Hering both adopt 7,000 cubic feet per second as their estimate of maximum flow from Charles above Waltham, combined with the drainage entering below.

Mr. Hale's investigations show a flow of only half this, or about 3,500 cubic feet per second in the worst flood of the past half-century.

Mr. Stearn's estimate (see p. 46 of Appendix to report of Joint Board in 1894) was 4,900 cubic feet per second. This was intended, Mr. Stearns tells me, to be an outside figure, and the Hale estimates indicate it ample and safe.

Investigations by R. A. Hale, C.E.

LAWRENCE, MASS., Nov. 28, 1902.

J. R. FREEMAN, Esq., *Engineer Charles River Commission, Boston, Mass.*

DEAR SIR: — In regard to the flood discharge of the Charles River, I present the following results. Examinations were made in three different localities, as follows: —

1. At Newton Upper Falls, Phipps & Train silk mill.
2. At Waltham, Boston Manufacturing Company.
3. At Watertown, Ætna mill.

1. At Newton Upper Falls the overfall of the dam is about 43 feet in length at the crest. The end of the overfall towards the mill has plank piling extending up stream from the crest, giving a uniform section of approach; and the opposite end of the overfall terminates in a rough ledge, in which the section is irregular; and when the depth on the crest exceeds about four feet, the water flows over the irregular ledge for a length of about 50 feet, in addition to the usual overfall. From an interview with the master mechanic, who has been at the mill for a period of more than twenty years, it was stated that the flood of 1886 was the greatest that had ever occurred in the memory or experience of any one in the vicinity or connected with the mill, and the records show a depth of 6 feet passing over the crest of dam.

The quantity passing the dam with this depth would be 2,008 cubic feet, and assuming one-third more in wasting over the ledges would give 2,680 cubic feet per second, or from 144 square miles of drainage area 18.6 cubic feet per second per square mile. The experience has been that an ordinary freshet every year will vary between the limits of 36 and 48 inches in depth, corresponding to a quantity of 800 to 1,000 cubic feet, or a yield of 5.6 to 7 cubic feet per second per square mile. In 1902 a freshet occurred of a depth of 53 inches, giving 1,440 cubic feet per second, or a yield of 10 cubic feet per second per square mile; but this is not likely to occur oftener than in a period of six or eight years.

2. At the Boston Manufacturing Company, Waltham, Mr. Jones, the master mechanic, states that the freshet of 1886 was the highest ever known during his experience of twenty-five years; and the records of the Boston Manufacturing Company taken since 1877 show this height of 21 inches to be the maximum of any recorded heights. This height has not been previously reached in the memory of any person connected with the company. The height of 21 inches on the gauge corresponds to a depth of 3.48 feet on the crest of the dam; and, from a measurement made of the bays in the dam, a quantity of 2,800 cubic feet per second was discharged over the dam and 480 cubic feet per second through the wheels, making a total of 3,280 cubic feet per second.

Or, from a drainage area of 162 square miles, would correspond to 20.2 cubic feet per second per square mile. At this time all the flashboards were removed from the dam, and no obstructions existed.

During ordinary freshets it is the custom to remove a portion of the flashboards as occasion requires, but no record is kept of the amount of boards removed, and the recorded heights of water by the gauge give no indication of the amount of water passing.

3. At the Ætna mills, Watertown, the freshet of 1886 is the greatest of any known height at this mill; and from marks furnished by Mr. Mayo, master mechanic, showed 3 feet in depth flowing over the dam. In addition, the wheel gates were open, discharging water, and at the west end of the dam at the wool house the water flowed through an open bulkhead and arches under the mill estimated at 108 square feet, and a velocity of 6 feet per second, or 648 cubic feet per second. Mr. Mayo states the dam to be submerged, so there was probably not over 1 or 2 feet difference in the surface above to below the dam. The velocity of approach must be 7 or 8 feet per second, and as an estimate the discharge might be equivalent to 3.5 feet in depth over free weir or 2,775 cubic feet per second; at south end, 648 cubic feet per second; at wheels, 122 cubic feet per second; total of 3,545 cubic feet per second; or, on a drainage area of 198 square miles, 18 cubic feet per second per square mile. The conditions were such at this dam that the result is more of a general estimate than of a closely measured quantity.

The ordinary freshets have a range of from 18 to 20 inches in depth over the dam. During 1902 the maximum height of 2 feet was reached. The following shows the yield: —

Depth on Dam (Inches).	Quantity passing (Cubic Feet per Second).	Cubic Feet per Second per Square Mile.
Eighteen,	1,120	5.7
Twenty,	1,216	6.1
Twenty-four,	1,500	7.6

The quantity passing includes the quantity drawn by the wheels in each case. A summary of the various localities is given in the following table: —

	Newton Upper Falls. — Drainage Area equals 144 Square Miles.		Waltham, Boston Manufacturing Company. — Drainage Area equals 162 Square Miles.		Watertown, Ætna Mills. — Drainage Area equals 198 Square Miles.	
	Cubic Feet per Second for 24 Hours.	Cubic Feet per Second per Square Mile.	Cubic Feet per Second for 24 Hours.	Cubic Feet per Second per Square Mile.	Cubic Feet per Second for 24 Hours.	Cubic Feet per Second per Square Mile.
Freshet of 1886,	2,680	18.6	3,280	20.2	3,545	18.0
Ordinary freshet,	800 to 1,000	5.6 to 7.0	–	–	1,120 to 1,216	5.7 to 6.1
Freshet of 1902,	1,380	10.0	–	–	1,500	7.6

The Waltham location is the best situation for determining the extreme freshet flow, owing to the free overfall between definitely fixed walls, and the other locations may be considered as corroborating the Waltham flow.

In ordinary freshets the uncertainty about the flashboards at the Waltham dam renders the Newton Upper Falls and Watertown localities more definite in estimation of quantities.

Respectfully yours,

Richard A. Hale, *Civil Engineer.*

Details of Computation of Flood Discharge.

LAWRENCE, MASS., Dec. 1, 1902.

J. R. FREEMAN, Esq., *Engineer Charles River Commission, Boston, Mass.*

DEAR SIR: — In addition to the results of the estimates for flood discharges of the Charles River, the following details of the computation are given. At the Newton Upper Falls dam the section at the crest is somewhat similar to the Essex Company's dam at Lawrence, and the formula deduced by J. B. Francis, C.E., for the flow over a dam of such section, was used, — Q. = 3.012 L. H. 1.53. With a depth of 6 feet, giving 46.713 cubic feet per second per foot in length, and for 43 feet = 2,008 cubic feet per second. The amount flowing over the ledges was somewhat in the nature of an estimate, as there was considerable irregularity, and from an inspection without instrumental measurements it was concluded that an amount of about one-third more would pass over the ledges. This quantity of 669 cubic feet per second for a length of 50 feet would correspond to about 2.5 feet in depth; and, as the quantity would begin to flow over the ledges at about 4 feet in depth on dam crest or slightly less depth in some places on the ledges, there would be velocity of approach to be added to obtain the depth of 2.5 feet above stated. A line of levels across the ledge would determine this more exactly, but the irregularity of the ledges would not justify any great amount of detail.

The amounts corresponding to 3 and 4 feet in depth are deduced from the same formula, and allowing 60 cubic feet as passing the wheel, —

Giving for 3 feet, 740 + 60 = 800 cubic feet per second.
Giving for 45 inches, 940 + 60 = 1,000 cubic feet per second.
Giving for 48 inches, 1,070 + 60 = 1,130 cubic feet per second.
Giving for 53 inches, 1,380 + 60 = 1,440 cubic feet per second.

At the Waltham dam the J. B. Francis formula for the Lawrence dam was used.

The iron supporting the flashboards forms an obstruction at each bay, which was measured.

The average length of 26 bays, with two end contractions, was 5.54 feet, and there were also two bays with one end contraction each.

The effective length was used, correcting according to the weir formula; and the flow over dam was found to equal 2,801 cubic feet per second. The wheels on 8 feet fall with gates wide open equal 479 cubic feet per second, making a total of 3,280 cubic feet per second.

At the Ætna mills the Lawrence dam formula was used, and, with the high velocity of approach which must have existed with the low dam, the depth of 3 feet was considered as equivalent to a clear discharge of 3.5 feet in depth. The dam is submerged, and there is some uncertainty in regard to this amount of submersion; and, as stated before, the figures are more in the nature of an estimate than an exact measurement.

In the ordinary condition of freshets with 18 inches in depth the quantity was 798 cubic feet per second, wheels 122 feet, and an estimate of 200 cubic feet passing south end of dam, making 1,120 cubic feet per second.

With 20 inches in depth, Q. = 894 + 322 = 1,216 cubic feet per second.
With 24 inches in depth, Q. = 1,179 + 322 = 1,501 cubic feet per second.

The length of the dam was considered as 135.5 feet, as this was measured a few years ago.

Respectfully yours,

RICHARD A. HALE, *Civil Engineer.*

Appendix No. 17.

Concerning the Influence of the Charles River Basin upon the Temperature of the Surrounding Air.

By John R. Freeman.

There is something attractive in the idea of a basin refilled twice each day by cool ocean water, and the question of how far the proposed dam might change the temperature over the adjacent territory was considered worthy of careful study.

Previous Observations.

Observations by Dwight Porter, C.E. — The observations reported by Professor Porter (evidence, p. 426) do not give the temperature over the land adjacent to the basin and at different distances away from it, but only give comparisons between the temperature of the air *down near the surface of the water*, as observed from a boat *in the middle of the basin*, and the temperature observed on top of the post-office building.

The air down close to the water may be considerably cooler than up at the level of a foot passenger crossing the bridge.

It is stated by Professor Porter that observations as to the air temperature over the proposed basin were made under his direction on five days scattered through August, 1894, from a boat anchored half way across the basin, opposite Exeter Street. He says: "Comparisons . . . showed the air temperature at the boat to be uniformly lower than the air temperature at the signal service station by amounts ranging all the way downward from 8 degrees."

Professor Porter's four diagrams, "N," "O," "P," "Q" (see pp. 425, 427 of evidence), of observation in August, 1894, show an average of *about 3 degrees cooler air at this boat* near the middle of the basin on representative hot, sunny days in mid-summer, when the water itself was from 11 to 21 degrees (average 13 degrees) cooler than the air.

I have obtained from the Weather Bureau the records of sun and wind for these days, and present this, in addition to the data presented in Professor Porter's report, in the following table: —

Temperatures at Boat on Charles River compared with Temperatures on Top of Boston Post-office (Degrees Fahrenheit).

[From Report of Prof. Dwight Porter and Records of United States Weather Bureau.]

Date and Hour, 1894,	August 7.					August 8.					August 9.			August 10.			August 24.					Average.
	2 P.M.	3 P.M.	4 P.M.	5 P.M.	6 P.M.	10 A.M.	11 A.M.	12 M.	1 P.M.	2 P.M.	11 A.M.	12 M.	1 P.M.	3 P.M.	4 P.M.	5 P.M.	10 A.M.	11 A.M.	12 M.	1 P.M.	2 P.M.	
Temperature of air at post-office,	86.0	86.0	85.0	84.0	81.0	83.0	87.0	89.0	89.0	88.0	82.0	82.0	82.0	73.0	72.0	72.0	79.5	83.0	86.0	88.0	88.5	-
Temperature of air at boat,	81.6	81.6	81.3	81.0	79.3	79.0	80.0	84.6	84.6	85.5	78.8	79.4	79.0	72.3	72.0	71.0	78.0	81.0	83.3	84.6	84.7	-
Cooler at boat,	4.4	4.4	3.7	3.0	1.7	3.9	7.0	4.4	4.4	2.5	3.2	2.6	3.0	0.7	0.0	1.0	1.5	2.0	2.7	1.4	3.8	2.9
Temperature of water opposite Exeter Street.	74.2	72.0	70.6	69.9	70.3	70.5	71.0	70.4	70.3	70.0	71.0	71.2	70.7	70.3	70.3	69.7	67.7	69.0	68.0	67.5	67.3	-
Water cooler than air at post-office,	11.6	14.0	14.4	14.1	10.7	12.5	16.0	18.6	18.7	18.0	11.0	11.0	11.0	2.7	1.7	2.3	11.8	14.0	18.0	20.5	21.2	13.0
Per cent. total sunshine,	-	100	100	70	20	100	100	100	100	100	100	100	100	100	60	70	100	100	100	100	100	-
Direction of wind,	-	SW	W	W	SW	SW	SW	SW	SW	SW	SW	W	W	NW	NW	N	W	SW	SW	SW	SW	-
Wind movement (miles per hour),	-	18	16	16	14	11	13	16	13	13	13	16	13	12	15	13	10	10	12	12	13	-
Predicted tide at Navy Yard,	High tide, 4.05 P.M.					Low tide, 10.40 A.M.					Low tide, 11.20 A.M.			High tide, 6.15 P.M.			Low tide, 10.32 A.M.					

Professor Porter states in letter, Sept. 15, 1902, that air temperatures were not measured by himself, but were undoubtedly taken in the shade, probably in the shadow of the observer. Thermometers were from the physical laboratory of the Massachusetts Institute of Technology, and had been verified by a standard.

Observations by T. Howard Barnes, C.E. — Mr. T. Howard Barnes, C.E., Boston, has for some years past taken special interest in certain studies of temperature in reservoirs, and reports the following observations: —

On July 2, 1901, an exceptionally hot day (91 degrees F.), he found the air about four or five feet above street level, close to the Boston end of Harvard bridge, at about 4 P.M., was of just the same temperature as at the corner of the Common, opposite the State House, and the same as reported by the Weather Bureau at top of post-office. The breeze was then about sixteen miles an hour from the south-west, and was thus parallel to edge of basin, but not across the basin to the position of the above observation. Five minutes later, at four or five feet above street level, on the embankment wall five hundred feet from the bridge, he found the temperature 2 degrees cooler, with the wind coming across the basin to this point. At about the same time the temperature down near the water level was 86 degrees; that is, *the air down near the water level was 5 degrees cooler than at top of embankment* at about the same time, and the water itself, at two inches depth, had a temperature of 77 degrees, and was thus 9 degrees cooler than the air.

On July 15, 1901, at about 11 A.M., with a wind reported at thirteen miles an hour from south-west, Mr. Barnes found the temperature of air, *about 4 feet above the water*, from a boat midway of basin was 83 degrees, which was 4½ degrees cooler than the temperature of the air noted just previously while riding along Cambridge Street, and was 3½ degrees cooler than the temperature reported at the Weather Bureau station on top of the post-office for that hour. The temperature of the surface water in the basin meanwhile was 72.3 degrees or 15 degrees cooler than the air.

Mr. Barnes' observation thus agrees, in a general way, with Professor Porter's, in finding the temperature of the air *near to the water surface, as from a boat in middle of basin, about 3 degrees cooler on a hot day than the air at top of post-office or in the streets*; but it also brings out the observation that this comparative coolness was considerably greater at a level down close to the water surface than up at the street level; and that even on the leeward side of the basin, up at the street level, it was only about 2 degrees cooler than at the Weather Bureau station or in the streets around the State House, although the water itself was at that time 15 degrees cooler.

These observations of Mr. T. Howard Barnes, while very interesting and suggestive, are obviously too few to be conclusive.

There is an abundance of strong personal opinion to be had, to the effect that the basin exerts a great influence in cooling the air.

On p. 312 of evidence Mr. L. S. Dabney quotes Dr. Derby to the effect that "on summer days there was a difference of 3 or 4 degrees *near* the basin and in other parts of the city."

On p. 336 Mr. Gamaliel Bradford says that the wind blowing over the present basin at the Harvard bridge is cool and refreshing on the hottest days; on p. 337 he quotes Mr. Viaux, in 1894, as understanding Professor Porter's testimony to the effect that with fresh water substituted for salt the breeze would be 10 to 15 degrees warmer (Professor Porter did not say this); and on pp. 337 and 338 quotes statements, made years ago (at the hearings of 1866) by Oliver Wendell Holmes and Louis Agassiz, laying especial emphasis upon "the cool fresh air from over the salt water," and "the salubrious influence of such a large sheet of sea water."

New Observations on Temperature, 1902.

This question of cooler air on hot days is one that appeals to popular interest, and there is danger that the sensation of coolness and comfort which comes merely from motion of the air, as by a fan or by the unrestricted sweep of the wind, may be confused with actual coolness of the air. That *the sensation of coolness and comfort in warm weather depends more upon the breeze than upon the absolute temperature* is a matter of universal experience. Warm air in motion may feel cooler than still air which is of a much lower temperature. Therefore, the popular opinions quoted on p. 473 were considered inconclusive, and the few thermometer readings reported by Professor Porter and Mr. T. H. Barnes were plainly insufficient to establish the facts for the region bordering the basin.

I therefore made careful measurements, on a more accurate and extensive scale, to determine the actual atmospheric temperature under present conditions at various points over and around the Charles River basin, for comparison with simultaneous measurements of the temperature at various points in Boston and Cambridge remote from the basin.

Scope of Observations of 1902. — We established thermometer measurements at twenty stations located all the way from Boston light to Norumbega, and also availed ourselves of measurements regularly taken at the United States Weather Bureau station on Boston post-office, at Harvard observatory, at Chestnut Hill reservoir and at the Blue Hill observatory. In every case the instruments used for these measurements were verified by comparison with accurate standards.

At ten of these stations "Draper self-recording thermometers" were used, each of these giving a continuous record throughout the twenty-four hours, seven days in the week. At the other stations, two or three, or more, observations were taken in the course of the day with good ordinary mercurial thermometers that had been standardized. These other mercurials were exposed in the shade with ordinary care by employees of the park department and others.

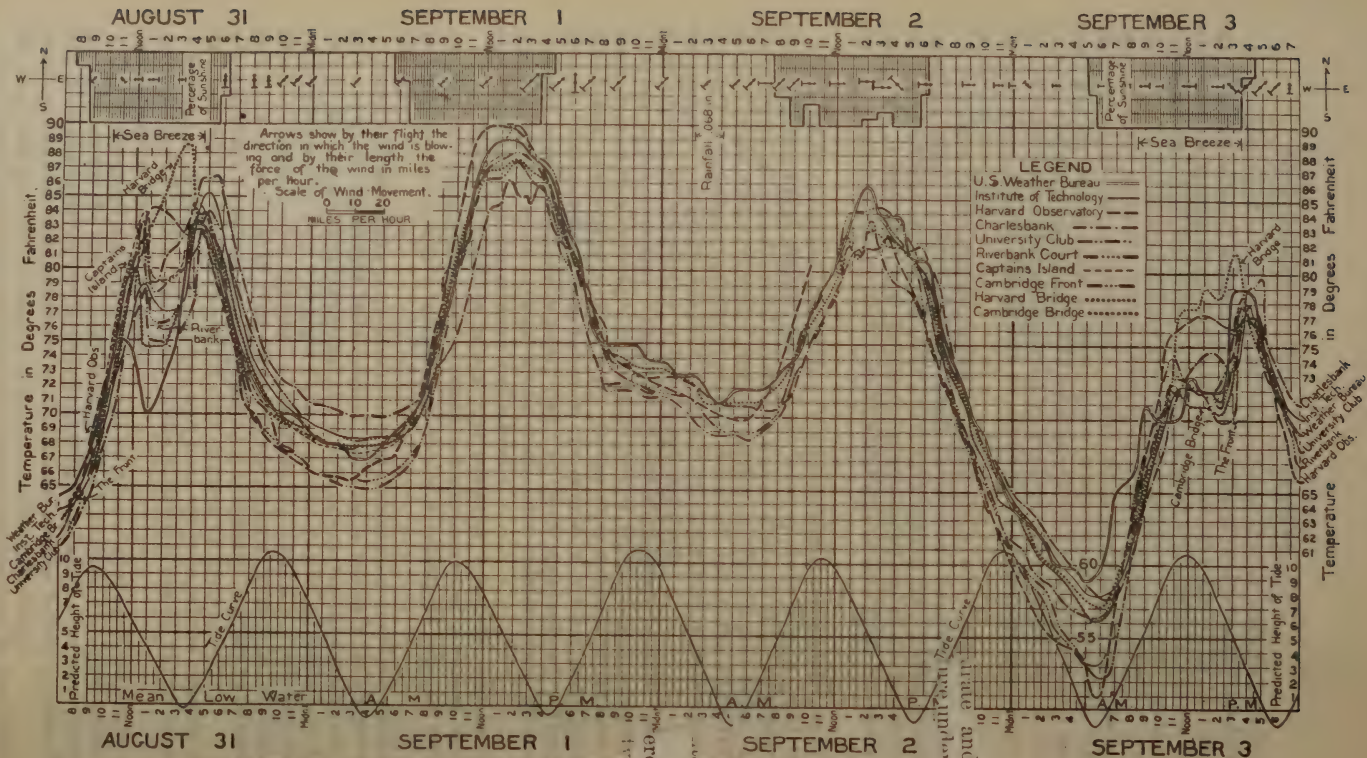
Great care was taken to select representative locations, and to so conduct the observations as to obtain a high degree of accuracy, and to learn the comparative temperature under a variety of summer conditions.

These thermometers were observed continuously for about ten weeks, and one of the important facts learned was that *to measure the temperature of the air and be certain that the results are correct and fairly representative within say 2 degrees F. is a matter requiring great care in choice of location and exposure of instrument;* and, if a recording instrument is used, be it even of the grade ordinarily used in scientific observatories, continual expert attention is necessary in order to be sure that the record is not frequently 2 or 3 degrees or more in error.

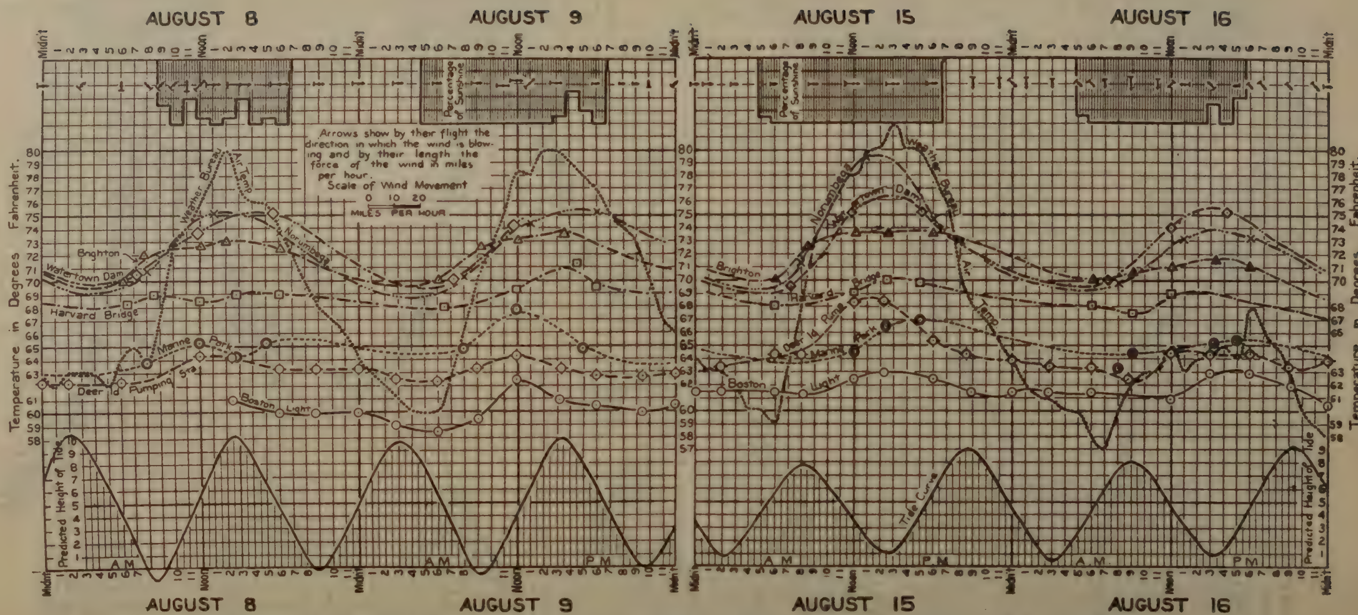
By means of great care and frequent tests we reduced the chances of error so that I believe the mean values following can be relied on as certain within less than 1 degree.

Out of the great mass of data secured by the observation of all of these instruments for the eighty days from June 25 to Sept. 15, 1902, covering the hottest portion of the past year, I have selected all of the hottest sunniest days and compared the temperatures for the hottest portion of the day, and present the results in the two tables following.

From these it will be seen that the average temperature in the immediate vicinity of the basin and directly over it is only 1.5 degrees cooler,



EXAMPLES SHOWING CHARACTERISTIC FORM OF THERMOGRAPH CURVES



TEMPERATURE OF WATER. BOSTON HARBOR AND CHARLES RIVER.

and around the shores of the basin averaged only 1.1 degrees cooler, than the mean of the observed temperatures at Weather Bureau, Institute of Technology and Harvard observatory, and *it is thus conclusively proved that no noteworthy loss of cooling influence of the basin will be suffered because of the proposed dam.*

The curves drawn automatically on the thermograph charts were replotted to an exaggerated scale of 1 degree Fahrenheit to a centimeter and 1 hour to 1 centimeter, all on a single chart, together with the observations of mercurial thermometers at other stations. A small but typical portion (one-twentieth of the whole chart) is reproduced on one-fifth the original scale on the next page. The percentage of total sunshine and the direction and force of the wind as reported by the Weather Bureau were also plotted on this chart, also the height of tide.

The temperatures of the water measured at the different stations all of the way from Boston light to Norumbega were also plotted on the same chart, but have been reproduced in a separate diagram, in order to avoid confusion of lines on the reduced scale of the engraving.

Limited Scope of the Sea Breeze. — The varying direction of wind was quickly found to have an important influence, and the influence of an easterly wind, "the Boston sea breeze," was beautifully shown.

The curves of August 31 and September 3, here reproduced, show this, although less plainly than the original large scale plotting.

It is of great interest to notice how quickly the temperature drops when the wind turns to the eastward, and that the influence of the sea breeze fades quickly as it moves inland.

For example, on August 31 the temperature of the air rose rapidly until 11 A.M. The wind then veered around to the east, and by 1 P.M. the temperature at the post-office had fallen 5 degrees, instead of rising 7 degrees, as it would have done in the same time with the ordinary south-westerly wind. A corresponding drop is noted at each station, but the cooling effect is progressively less inland. At the Institute of Technology it was 7 degrees warmer than on top of the post-office, and at Harvard observatory it was 14 degrees warmer. On September 3 similar effects are noticed, although less extreme.*

The Warming of the Water. — The next diagram exhibits the progressive change in the temperature of the water as we go inward from Boston light, and shows how soon its temperature responds to the sun's heat at midday, and also exhibits the influence of the tide. The first two days selected had a full tide in the heat of the day, and on the next two days the ebb had nearly run its course at the hour of maximum air temperature. The air temperature is plotted on this sheet of water temperatures for comparison. On the last day here shown the air temperature was lowered by a sea breeze.

* On both these days the thermograph on the Harvard bridge was affected much less by the cooling breeze than most of the other instruments, and the Charlesbank instrument also somewhat less. The reason is not clear.

***Temperature of Air** at and near Boston on All Bright, Sunny Days with no East Wind between June 28 and September 12, 1902.*

Degrees Fahrenheit. From plotted curves. Corrected for thermometer errors. Maximum and minimum corrected for lag. Interpolations ( ). Mean of observations at 10 A.M., 12 M., 2 P.M. and 4 P.M.

AT STATIONS NOS. 1 TO 14. — Observations were taken continuously by self-recording instruments exposed in fully ventilated white wooden shelters, in the open air, frequently checked and corrected daily by standardized mercurial thermometers.

AT STATIONS NOS. 15 TO 25. — Observations were occasionally taken through the day by standardized mercurial thermometers hung in the shade, in the open air. As here given they are reduced to the nearest even hour according to change by the thermograph curves.

	DATE.																					
	June 28.	July 2.	July 4.	July 8.	July 9.	July 12.	July 13.	July 14.	July 15.	July 28.	August 7.	August 9.	August 12.	August 13.	August 14.	August 15.	August 26.	September 1.	September 2.	September 8.	September 12.	Average of 13 days, July 15–September 12.
Chestnut Hill, . . .	73.7	-	-	-	88.6	80.5	84.7	-	(84.8)	82.0	74.2	77.1	(74.6)	69.4	74.9	79.2	77.8	87.5	83.0	77.8	73.4	78.9
Harvard observatory, .	-	-	-	-	-	-	-	-	(85.0)	(82.0)	(75.5)	(77.8)	(74.8)	69.1	75.2	79.5	77.6	87.6	(82.8)	76.9	74.6	78.3
Institute Technology, .	73.7	74.0	74.6	78.2	85.8	-	-	87.8	85.4	80.6	74.6	76.0	72.6	69.2	74.1	78.3	76.2	(86.6)	(82.6)	74.6	72.8	77.2
Boston P. O., U. S. W. B.,	75.0	75.2	79.0	79.2	88.0	79.5	82.7	88.0	84.0	81.0	74.7	77.0	74.0	69.0	75.2	78.5	77.0	86.0	82.0	76.7	72.7	76.9
Standard mean, . .	**74.1**	**74.6**	**76.8**	**78.7**	**87.5**	**80.0**	**83.7**	**87.9**	**84.8**	**81.4**	**74.7**	**77.0**	**74.0**	**69.2**	**74.8**	**78.9**	**77.1**	**86.9**	**82.6**	**76.5**	**73.4**	**77.8**
Cambridge Bridge, . .	77.1	78.3	79.9	76.9	86.1	78.1	86.2	86.8	85.3	-	72.7	-	-	-	-	-	76.0	-	-	76.1	71.7	-
Harvard Bridge, . .	73.0	76.2	-	-	-	-	82.2	85.7	82.8	79.2	72.7	74.5	72.7	68.6	74.0	76.4	76.0	85.4	80.2	75.2	73.5	76.3
Basin mean, . .	-	-	-	-	-	-	-	-	84.1	79.2	72.7	74.5	72.7	68.6	74.0	76.4	76.0	85.4	80.2	75.6	72.6	76.3
Amt. above standard,	-	-	-	-	-	-	-	-	**−0.7**	**−2.2**	**−2.0**	**−2.5**	**−1.3**	**−0.6**	**−0.8**	**−2.5**	**−1.1**	**−1.5**	**−2.4**	**−0.9**	**−1.8**	**1.5**
Pinckney Street, . .	73.9	-	77.2	79.1	87.0	77.5	81.2	85.5	84.0	78.2	72.9	-	-	-	-	-	-	-	-	-	-	-
Charlesbank, . . .	72.9	72.9	74.1	77.1	87.4	77.3	80.3	84.5	83.4	(78.9)	(73.0)	(74.5)	71.3	67.0	73.7	77.2	77.9	82.6	79.5	72.1	74.0	75.8
University Club, . .	-	71.2	75.6	77.9	85.8	78.2	79.4	85.5	85.8	78.8	72.9	74.4	71.1	66.6	72.6	76.2	74.2	85.2	79.0	74.6	73.0	75.7
Cambridge Front, . .	-	-	-	-	-	81.0	85.3	90.3	86.1	80.7	75.3	77.8	74.4	70.0	77.3	80.7	81.6	86.5	81.5	77.0	72.2	78.5

Riverbank,	–	73.5	78.3	82.0	89.7	83.5	–	–	86.4	80.9	74.1	78.1	(73.0)	(68.6)	74.3	78.0	78.9	84.7	(80.1)	72.2	73.1	77.1
Captain's Island,	71.4	73.3	75.9	76.9	86.7	78.8	81.4	86.2	84.8	79.9	73.1	75.3	70.9	67.6	73.6	77.5	77.0	(86.0)	(79.8)	75.9	73.4	76.3
Basin shore mean,	–	–	–	–	–	–	–	–	85.3	79.8	73.7	76.0	72.1	68.0	74.3	77.9	77.9	85.0	80.0	74.4	73.1	76.7
Amt. above standard,	–	–	–	–	–	–	–	–	+0.5	–1.6	–1.0	–1.0	–1.9	–1.2	–0.5	–1.0	+0.8	–1.9	–2.6	–2.1	–0.3	–1.1
Forest Grove, Aub'ndale,	72.2	–	79.1	80.5	–	80.0	84.4	89.4	(85.7)	79.8	74.0	76.4	73.0	70.4	74.2	78.9	76.2	(86.9)	(80.7)	(76.8)	73.7	77.5
Norumbega,									84.6	81.4	76.7	75.6	72.0	68.6	73.8	78.4	74.6	84.5	81.3	74.5	72.6	76.7
Bemis dam,									86.4	82.1	77.0	77.7	73.3	73.1	(75.8)	79.8	79.2	(86.5)	84.7	(76.5)	72.1	78.8
Watertown dam,									84.2	89.3	76.7	74.7	73.0	69.3	72.8	76.3	75.8	(84.3)	80.9	73.3	72.2	77.1
Brighton Speedway,									88.0	78.2	70.6	72.0	72.2	66.7	72.8	79.4	74.6	82.7	79.0	72.0	69.7	75.2
Up-river mean,									85.8	82.2	75.0	75.3	72.7	69.6	73.9	78.6	76.1	85.0	81.3	74.4	72.1	77.1
Amt. above standard,									+1.0	+0.8	+0.3	–1.7	–1.3	+0.4	–0.9	–0.3	–1.0	–1.9	–1.3	–2.1	–1.3	–0.7
United States Navy Yard,									(85.5)	82.0	74.0	78.8	76.8	70.6	76.9	80.9	79.1	(86.5)	82.1	78.3	73.6	78.7
Marine Park,									(80.8)	79.5	71.2	74.0	70.3	66.3	72.0	74.2	75.1	82.7	78.1	72.7	68.9	74.3
Deer Island pumps,									80.6	74.6	69.2	71.7	71.5	(66.7)	73.7	75.3	75.7	79.6	77.8	73.8	71.1	73.9
Deer Island Light,									(80.7)	76.8	70.9	73.5	71.9	66.8	72.6	79.6	74.1	80.0	77.3	69.9	78.3	74.8
Revere Beach,									82.9	80.3	(71.6)	77.6	76.9	(68.3)	70.6	76.9	74.1	(82.0)	80.9	72.2	(73.5)	76.0
Nantasket Beach,									(85.1)	80.1	75.2	79.0	75.5	71.0	76.9	78.1	78.6	(84.2)	(83.1)	(74.4)	(75.7)	78.1
Harbor mean,									82.6	78.9	72.0	75.8	73.8	68.3	73.8	77.5	76.1	82.5	79.9	73.5	73.5	76.0
Amt. above standard,									–2.2	–2.5	–2.7	–1.2	–0.2	–0.9	–1.0	–1.4	–1.0	–4.4	–2.7	–3.0	+0.1	–1.8
Boston Light,									(82.5)	77.4	(72.4)	75.0	75.1	73.0	76.1	78.4	78.1	80.0	77.1	71.3	69.1	75.8
									–2.3	–4.0	–2.3	–2.0	+1.1	+3.8	+1.3	–0.5	+1.0	–6.9	–5.5	–5.2	–4.3	–2.0*
Time high tide,									–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mean direction and force of wind,									–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sun or cloud,									–	–	–	–	–	–	–	–	–	–	–	–	–	–

Not included in average. Record probably in error on account of sun striking instruments in afternoon through window in shelter.

REMARKS: Until August 28 the thermographs at University Club, Riverbank Court, Captain's Island and Harvard Bridge were in their "first positions," subject to disturbing influences of adjacent buildings.

* This difference is surprisingly small, notwithstanding the well-known influence of the "land breeze" at Nantasket, — the prevailing south-westerly wind of summer. This table includes only the hottest days of the summer, when there was no sea breeze.

Temperature of Water *in Boston Harbor and Charles River, 1902.*

Mean of temperature, 10 A.M., 12 M., 2 P.M. and 4 P.M., on all bright, sunny days. Taken from plotted curves. Interpolations thus ( ).

Degrees Fahrenheit. All thermometer readings corrected to standard. Observed by immersing thermometer promptly in a pailful of water taken from near surface and stirring it until settled. Some of values stated below are taken from curves drawn through observations of high tide, low tide, noon, 6 A.M. and 6 P.M., etc.

	July 15.		July 28.		Aug. 7.		Aug. 9.		Aug. 12.		Aug. 13.		Aug. 14.	
	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.
Air — Boston standard mean, (see preceding table),		84.8	⅔ Flood.	81.4	High.	74.7	⅔ Flood.	77.0	Low.	74.0	Low.	69.2	Low.	74.8
Norumbega,		79.1		70.2		75.1		70.0		74.8		73.8		73.2
Forest Park,		79.1		72.8		75.7		72.8		76.6		74.3		75.8
Bemis dam,		79.8		69.7		76.5		70.8		75.1		73.3		74.3
Watertown dam,		79.6		70.7		74.4		75.6		75.2		72.3		73.5
Up-river mean,		79.4		70.8		75.4		72.3		75.4		73.4		74.2
Amt. above harbor mean,		**+14.4**		**+5.5**		**+9.9**		**+7.3**		**+10.2**		**+9.4**		**+8.7**
Brighton,		79.1		71.7		72.9		73.2		74.5		71.9		71.7
Captain's Island,		70.1		(68.6)		70.2		70.3		71.0		70.7		69.1
Harvard Bridge,		69.4		68.1		69.3		70.0		71.2		(69.4)		69.2

	Aug. 15.		Aug. 26.		Sept. 1.		Sept. 2.		Sept. 8.		Sept. 12.		Average of 13 days, July 15–September 12.
	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	Tide at 1 P.M.	Temperature.	
Air — Boston standard mean, (see preceding table),	¾ Ebb.	78.9	½ Flood.	77.1	½ Ebb.	86.9	⅓ Ebb.	82.6	½ Flood.	76.5	Low.	73.4	77.8
Norumbega,		74.2		74.5		76.2		78.2		70.8		69.3	73.8
Forest Park,		75.9		76.1		(76.4)		(80.1)		(73.2)		71.4	75.4
Bemis dam,		76.3		72.2		76.9		79.0		73.3		72.6	74.6
Watertown dam,		76.3		72.2		76.9		78.1		71.7		72.4	74.5
Up-river mean,		75.7		73.7		76.6		78.8		72.2		71.4	74.6
Amt. above harbor mean,		**+10.7**		**+8.0**		**+7.4**		**+11.9**		**+8.7**		**+7.9**	**+9.3**
Brighton,		73.4		71.9		76.0		74.5		70.0		73.4	73.4
Captain's Island,		70.9		67.7		(71.7)		(71.5)		(67.0)		(67.9)	69.7
Harvard Bridge,		69.4		68.8		(71.6)		(73.2)		(68.2)		68.3	69.7

Union Boat Club,	70.4	67.3	68.2	68.7	70.3	67.0	69.3	69.5	66.4	70.4	70.2	66.7	66.6	68.5
Cambridge Bridge,	69.9	66.2	65.7	67.5	68.3	67.5	68.0	68.4	66.5	(69.7)	69.3	66.3	66.8	67.8
Charles basin mean,	71.8	68.4	69.3	69.9	71.1	69.3	69.5	70.3	68.3	71.9	71.7	67.6	68.6	69.8
Amt. above harbor mean,	**+6.8**	**+3.1**	**+3.8**	**+4.9**	**+5.9**	**+5.3**	**+4.0**	**+5.3**	**+2.6**	**+2.7**	**+4.8**	**+4.1**	**+5.1**	**+4.5**
United States Navy Yard,	(65.0)	64.7	65.5	66.4	67.9	66.3	65.9	66.4	65.2	(69.9)	67.6	64.0	64.4	66.1
Marine Park,	(64.9)	65.9	69.2	66.1	65.5	64.2	65.6	65.3	66.6	67.8	67.5	65.6	63.9	66.0
Deer Island pumps,	63.9	64.0	63.9	63.7	63.8	(63.1)	65.4	67.3	65.6	68.8	67.6	63.1	62.9	64.9
Deer Island Light,	(61.6)	63.0	63.8	62.6	61.6	62.0	64.5	64.3	62.7	65.5	65.0	60.3	59.9	62.8
Revere Beach,	67.0	69.0	64.4	63.9	67.4	62.6	64.5	63.1	67.9	71.3	66.6	63.7	64.8	65.9
Nantasket Beach,	(67.4)	65.5	66.3	67.6	65.2	66.1	66.9	63.4	66.4	(71.7)	(67.0)	(64.1)	(65.2)	66.4
Harbor mean,	**65.0**	**65.3**	**65.5**	**65.0**	**65.2**	**64.0**	**65.5**	**65.0**	**65.7**	**69.2**	**66.9**	**63.5**	**63.5**	**65.3**
Boston Light,	61.3	61.2	(61.4)	61.2	60.8	61.2	63.3	62.4	63.2	64.0	62.8	59.7	59.8	61.7
Amt. above harbor mean,	**−3.7**	**−4.1**	**−4.1**	**−3.8**	**−4.4**	**−2.8**	**−2.2**	**−2.6**	**−2.5**	**−5.2**	**−4.1**	**−3.8**	**−3.7**	**−3.6**

Notes concerning the Methods of Observation used in determining the Comparative Temperature at Different Points about the Charles River Basin.

Self-recording Thermometers. — For the more important stations the Draper thermograph was used, principally because there were ten new instruments of this kind on hand in the laboratory of the Factory Mutual Insurance Companies immediately available for our use without expense.

While the Draper thermograph was found to be a more cheaply built instrument than the French Richard thermograph, a study of its mechanism showed that it was simple, skilfully designed, with few movable joints, with both lever arms long, and with apparently little liability to multiply errors, due to looseness or due to internal strain. Tests of the friction of pen upon its chart and of the power of the thermometric metal springs to pull the pen into the true position indicated that, when delicately adjusted, it would quickly right itself within 0.1 or 0.2 degrees after being distorted by slightly raising or depressing the pen. The promise of this degree of precision in daily work was not realized.

The clocks in the instruments were found to be poor timekeepers, feeble in driving power, and losing time toward end of the week; but all material error from this source was easily removed from the final record by our daily comparisons.

I had assumed that, by means of a careful daily comparison of each thermograph chart with the reading of a fine mercurial thermometer, we would be able to easily keep the final error or uncertainty of measurement within narrow limits, certainly within less than a degree, and this proved true for much the greater portion of the time; but to our great regret we found occasional unaccountable changes in this thermograph correction, so that during the last few weeks of the observations extra care was used, two comparisons per day with the mercurial thermometers were occasionally made of each thermograph, reading with magnifiers by estimation to tenths of degrees, and using all practicable care in manipulation, sometimes making the comparison with a rising and sometimes with a falling curve, and finally maximum and minimum thermometers were placed inside the shelter beside each thermograph.

Although commonly the change in correction between comparisons was not more than half a degree, it was found that without constant care the Draper thermographs could not always be trusted to continue in adjustment within 3 or 4 degrees in the course of the week. I can only at present account for this by a sort of molecular readjustment under the temperature strain, or change of "set" in the soldered union of the thin strips of dissimilar metals forming the thermograph springs.

The methods of test and calibration are described briefly on p. 483.

In general, we may say that the daily variation in correction for these Draper instruments, as thus cared for, were much more irregular than those reported for the Richard thermograph at the Blue Hill observatory. They were very much less than the variations in correction of the Richard thermograph at Harvard observatory, or than that of the Richard thermograph at Chestnut Hill, neither of which has recently received special care; and the vagaries of our thermographs were little, if any, greater than that of the Richard telethermograph at the Weather Bureau station on the Boston post-office.

Sometimes, for several days in succession, the error of the Draper would not change by more than half a degree; but again, at somewhat rare intervals, there would be a sudden unaccountable falling out of adjustment to the extent of 3 degrees.

While these Draper self-recording thermometers did not prove instruments of precision, or safe without frequent attention, and while I should hesitate to use them again for such important work, our daily comparisons, made in the middle of the day close to the time of day in which we are most interested, served to hold the error tolerably well under control, and in the long series of observations the instrumental errors doubtless balanced.

Calibration of the Mercurial Thermometers. — The two standards continually in use for our most precise work and for standardizing the

other instruments and testing their lag and error were two excellent and extremely sensitive Greene chemical thermometers, Nos. 9507 and 9522, with long cylindrical bulbs, procured from the maker five years before, and not recently exposed to any extremes of temperature.

Each degree Centigrade was represented by a space of nearly a quarter of an inch in length of graduation, and the graduations were one-tenth of a degree Centigrade apart, thus permitting reading by estimation under a magnifier with certainty to within one or two one-hundredths of a degree Centigrade.

We procured from Greene, of Brooklyn, a dozen very fine chemical thermometers, graduated to half degrees Fahrenheit, each degree being represented by $\frac{1}{12}$ inch in length of scale. These were thus easily read by estimation to one-tenth degree Fahrenheit.

These were used at Boston light, Deer Island light and at the other important stations where no thermograph was located, and were also used for the water temperatures, and one of these was used by the travelling observer in his daily comparisons and adjustments of the thermographs.

A remarkable fatality to these fine instruments appeared to follow placing them in the hands of certain of the keepers on whom we relied as observers at some of the stations; so we also procured about a dozen of the cheaper German chemical thermometers, graduated to single degrees, each degree represented by $\frac{1}{16}$ inch in length of scale, and read by estimation to one-fourth degree with ease.

All of the above thermometers were calibrated by comparison at several points covering our probable range of work with a standard thermometer in the physical laboratory of the Massachusetts Institute of Technology, and the following table of corrections was derived from plotting the results of this series of comparisons. All observed results have been corrected by the use of this table.

Table of Correction to Thermometers used in Investigations for Committee on Charles River Dam.

[Corrections to thermometers in degrees Fahrenheit.]

READING OF THERMOMETER IN DEGREES FAHRENHEIT.	GREENE.										GERMAN.									
	9507	9522	5864	5815	5821	5822	5826	5828	5829	8722	J. R. F. 1	J. R. F. 2	J. R. F. 3	J. R. F. 4	J. R. F. 5	J. R. F. 6	J. R. F. 7	J. R. F. 8	9	J. R. F. 12
	Degrees Centigrade.																			
32, ...	—0.1	—0.2	0.00	0.0	0.0	0.0	0.0	0.0	0.0	—0.5	-	-	—1.1	—0.0	—0.6	—0.5	—1.5	0.0	—0.5	-
35, ...	—0.2	—0.2	0.00	—0.1	—0.1	—0.1	0.0	0.0	—0.1	—0.4	-	-	—1.2	—0.2	—0.3	—0.4	—1.3	+0.3	—0.5	-
40, ...	—0.1	—0.1	0.00	—0.1	—0.3	—0.2	0.0	+0.1	—0.2	—0.3	-	-	—1.2	—0.3	—0.1	—0.2	—1.0	+0.6	—0.4	-
45, ...	0.0	0.0	+0.01	—0.1	—0.2	—0.1	—0.0	+0.1	—0.3	—0.2	—1.3	—1.4	—1.0	—0.5	—0.1	—0.2	—0.7	+0.4	—0.2	—1.0
50, ...	0.0	0.0	+0.02	—0.1	—0.2	—0.1	+0.1	0.0	0.0	—0.2	—0.7	—0.9	—1.0	—0.4	—0.1	—0.2	—0.7	+0.2	—0.1	—0.9
55, ...	0.0	0.0	+0.02	—0.2	0.0	0.0	0.0	—0.0	0.0	—0.3	—0.8	—1.1	—1.1	—0.3	—0.2	—0.1	—0.6	+0.1	+0.1	—0.9
60, ...	0.0	0.0	+0.03	—0.3	0.0	0.0	+0.1	+0.1	+0.1	—0.3	—0.9	—1.2	—1.1	—0.2	—0.3	—0.1	—0.5	+0.1	+0.1	—0.9
65, ...	+0.1	0.0	+0.03	—0.2	0.0	0.0	+0.1	0.0	+0.1	—0.3	—0.8	—1.2	—1.2	—0.2	—0.3	—0.1	—0.5	+0.1	+0.2	—0.8
70, ...	+0.2	0.0	+0.03	—0.2	0.0	0.0	0.0	+0.1	0.0	—0.3	—0.9	—1.2	—1.0	—0.2	—0.3	—0.2	—0.4	0.0	+0.2	—0.7
75, ...	-	-	+0.04	—0.1	+0.1	+0.1	+0.1	+0.1	+0.1	—0.3	—0.8	—1.3	—1.2	—0.3	—0.3	—0.2	—0.3	—0.1	+0.3	—0.7
80, ...	-	-	+0.04	—0.2	+0.2	+0.2	+0.2	+0.1	+0.2	—0.2	—0.9	—1.3	—1.0	—0.6	—0.4	—0.1	—0.3	—0.2	+0.3	—0.7
85, ...	-	-	+0.04	—0.2	+0.2	+0.2	+0.1	+0.1	+0.3	—0.2	—0.8	—1.4	—1.0	—0.8	—0.3	—0.1	—0.2	—0.2	+0.1	—0.6
90, ...	-	-	+0.04	—0.2	+0.1	+0.2	+0.1	+0.1	+0.3	—0.2	—0.8	—1.5	—0.8	—0.9	—0.2	—0.1	—0.1	—0.2	+0.2	—0.6
95, ...	-	-	+0.04	—0.2	+0.1	+0.1	+0.2	+0.2	+0.2	—0.2	—0.7	—1.6	—0.7	—1.0	—0.3	—0.1	—0.1	—0.2	+0.4	—0.6
100, ...	-	-	+0.04	—0.2	+0.1	+0.2	+0.1	+0.1	+0.1	—0.2	—0.6	—1.5	—0.6	—0.8	—0.5	—0.2	0.0	—0.3	+0.1	-
105, ...	-	-	+0.04	—0.3	+0.2	+0.2	+0.1	+0.1	+0.1	—0.3	—0.5	—1.5	—0.6	—0.6	—0.5	—0.3	+0.1	—0.2	+0.2	-
110, ...	-	-	+0.04	—0.1	+0.4	+0.3	+0.2	+0.2	+0.4	—0.3	—0.4	—1.6	—0.2	—0.5	—0.4	—0.2	+0.3	—0.3	+0.5	-

Calibration and Adjustment of Draper Thermographs. — These ten instruments were compared every day except Sunday with one of the standard Greene mercurial thermometers by an observer who visited each station in rotation, commonly between 9 A.M. and noon, but sometimes in the afternoon. Care was taken to expose the mercurial standard within the shelter for at least five minutes before reading it, and in our later work it was read at one-minute intervals for five minutes or more in each daily comparison, to make sure that it had settled.

The hours in whose temperatures we are most interested thus fell near the hour of daily calibration, and any error due to eccentricity of chart was also thereby guarded against.

The thermograph was ordinarily readjusted once a week, at the time of changing dials or charts. The position of its pen was read daily, but the correction used was determined later, in the office, by comparison under a magnifier of the line drawn by its pen upon the chart with the daily readings of the mercurial thermometer. The clock error was noted daily and proper correction made. Apparently the error due to reading or to comparison or to the chart should seldom have exceeded one-fourth of 1 degree F., but there were other errors to be considered; namely, those due to lag of instrument and those due to non-permanence in the adjustment of the metallic thermometric springs, and those due to local conditions of exposure, the last perhaps the most serious of all, for it is not an easy matter to protect against undue absorption of heat by a detached shelter exposed to the sun, however carefully ventilated, or to be certain that a shelter attached to the side of a building may not be influenced by air currents affected by the absorption and giving out of radiant heat by the walls of the building, or by some other adjacent object.

Comparison of Draper Thermograph with Weather Bureau Thermograph. — We set one of the Draper Thermographs up in the same shelter with the telethermograph (by Richard of Paris) in regular use at the Weather Bureau station on top of the Boston post-office, and ran it there for seventy-two hours without disturbance, and replotted the charts of the two instruments together on a largely magnified scale.

The curves ran remarkably close together, varying rarely more than one-half degree F. (which is the length of step of this telethermograph), often coinciding completely, and turning the corners of daily maximum and minimum in very close agreement; but after thus agreeing with remarkable precision all the time for fifty hours, there came one night, from 9 P.M. to 4 A.M., an unaccountable divergence of about 2 degrees (the Draper, the lower). Whichever instrument was out (apparently the Weather Bureau instrument) then righted itself, and the two instruments went on in close agreement to the end of this test. This test was very satisfactory.

Comparison with Harvard Observatory Thermograph. — We set another of our Thermograph shelters on the north side of a small wooden building, about twenty feet away from the thermograph shelter at Harvard observatory.

Unfortunately, the Richard thermograph belonging to the observatory was found to be so badly out of order that its readings were of almost no value, the correction to it, as shown by their mercurial instrument alongside it, frequently varying more than 5 degrees within a few hours. The variable shade of the trees in this location was unfavorable for precise comparisons. The director kindly had an assistant read our Draper recording instrument and the mercurial alongside it in our shelter simultaneously with the college instruments in the regular shelter, commonly four times per day and our Draper chart readings were corrected accordingly.

Determination of Lag of Thermograph. — Although our ten Draper thermographs were alike and exposed in similar shelters, and thus subject to supposably equal errors of lag, there were, as previously stated on p. 474, ten or more other stations used in our comparisons, where occasional readings were taken by the mercurial thermometers. Therefore it became of interest to learn how much lower the Draper instrument, with its larger mass to be heated, would stand during the morning, while the temperature was rapidly rising, and how much higher it would stand in the evening, when the temperature was falling.

The extra-sensitive Greene thermometers mentioned on p. 481 were used for this comparison, and were enclosed along opposite sides of the thermograph in a wooden box having small "windows," through which the instruments could be read.

The temperature was controlled by inserting electric lamps of various candle-power in the bottom of the box, and thoroughly mixing the air in the box by a small electric fan. In other experiments the air in the box was cooled with lumps of ice, great care being taken to give equal conditions of exposure, and some precautions taken to shield the instruments from direct radiation and to mix the air by a gentle current from the electric fan inside the comparator box.

It was in general found that with the temperature of the air rising at rates of from 5 to 10 degrees F. per hour, the Draper thermograph lagged behind the sensitive mercurials from 1 to 2 degrees F., and that with sharply defined changes, as from the rate of 5 degrees per hour upward to 5 degrees per hour downward, the Draper thermograph lagged about five minutes in reaching a maximum or a minimum temperature.

Successive experiments, with changed conditions, did not always repeat with the precision desirable, but the lag was nearly always within the limits just stated.

In the practical use of the instruments, the rate of rise of the temperature of the air on bright summer days is seldom more than from 3 to 4 degrees per hour between 7 A.M. and 11 A.M. The rate of fall of temperature after 6 P.M. is commonly at about the same rate. As the maximum temperature of the day is approached, the rate of rise becomes less rapid; and, as the minimum temperature is approached at night, the fall also becomes slow, the rate of change commonly only 1 or 2 degrees per hour. Therefore, at the time of occurrence of the maximum and minimum air temperature of the day, the lag is not an important factor, being probably nearly always less than one-half a degree.

The "inertia" of the instrument, if we may so term it, by which the temperature of instrument continues to rise for about five minutes after the maximum is past, tends toward balancing the greater lag error due to a more rapid rate of rise or fall.

Maximum and Minimum Thermometers. — We used these during the last week of our observations, exposing them in our thermometer shelters alongside the thermographs.

The eight instruments at hand were of English manufacture (marked J. Hicks, London), and differed from the United States Weather Bureau instruments in using alcohol as the expanding liquid.

We carefully compared all of these, at several temperatures, with the two special sensitive standard thermometers mentioned on p. 481, and applied the corrections thus found to all observations.

Since these maximum and minimum instruments were apparently more sluggish than our regular mercurial instruments with thin cylindrical bulbs, and presumably less sluggish than a thermograph, we measured their lag for various rates of rise and fall.

We found that, with the temperature of the air slowly rising at the rate of about 6 degrees per hour, the maximum and minimum instruments averaged readings about seven-tenths of a degree F. too low; and apparently the "inertia" of the instrument kept it rising about two or three minutes after a sudden change, as by shutting off the electric lamp in the comparator box.

The lag of these instruments in comparison with the sensitive mercurials was thus from one-half to three-fourths that of the Draper thermographs; and under the slow rate of actual rise and fall of temperature, 1 to 2 degrees per hour in the open air, ordinarily approaching a maximum or minimum, this could introduce no noteworthy error in our results.

These maximum and minimum readings were used for a further check on the thermograph charts.

It is of interest to note that the corrections finally adopted for use within the limits of our observations, or say 60 to 80 degrees F., for these Hicks instruments were not large. They were as follows: —

STATION.	Mark on Instrument.	Of Corrections for Maximum Index.	Of Corrections for Minimum Index.
"The Front," Cambridge, . . .	No. 1, . .	+1.3	+0.5
Middle of Harvard bridge, . . .	No. 2, . .	+1.3	+0.1
University Club, ...	No. 3, . .	+1.5	+0.3
Riverbank Court, ...	No. 4, . .	+0.9	+0.4
Charlesbank, ...	No. 5, . .	−0.1	−0.7
Institute of Technology, . . .	No. 6, . .	+0.8	−0.2
Captain's Island, ...	No. 7, . .	+0.5	−0.6
Middle of Cambridge bridge, . .	No. 8, . .	+0.6	−0.3

Thermometer Shelters and Locations. — These ten thermograph stations were selected with a view to securing representative locations around the basin, and with a view to making the exposure of the instruments favorable for precision of measurement. These locations and their relation to the meridian and daily range of sun on a mean date are shown in the four plates preceding.

These ten instruments were all alike, and shelters precisely alike were constructed for each. These wooden shelters were about eighteen inches wide by fourteen inches deep by twenty-four inches high, and were composed in part of sections of ordinary house blinds, in order to afford free circulation of air. All were painted a pale gray, intended to be the same as the present color of the Weather Bureau shelter, which has apparently become smoked and begrimed, but our painter inadvertently got the shade of our shelters a very little darker.

Considerations of cost, quickness of construction, portability and the temporary character of the experiment led to the use of a shelter smaller than the standard thermometer shelter used by the Weather Bureau. The metal thermometric springs in the Draper type of thermograph are again shielded by the case of the instrument, therefore it was thought that a smaller shelter could be tolerated.

The location, form of support and height above ground of the thermometer shelters at some of these locations were influenced by considerations of keeping the instruments free from jar and beyond the easy reach of curious or mischievous boys. The Pinckney Street location, set well out on a fire-escape balcony overlooking the water, although having a westerly exposure, appeared well adapted to show the effect of the unrestricted sweep of the south-west wind from over the basin; and the Charlesbank instrument was at first located on the side of the building nearest the water and most exposed to winds across it, which happened to be the westerly side.

In general, locations were at first availed of upon the shady side of buildings, away from air currents from windows, and safely distant from chimneys or other obvious causes of disturbance of atmospheric temperature.

The selection of some of the first positions was influenced by a desire to expose the sheltered instrument to the full force of the prevailing summer breeze from over the basin.

A later study of the influence of the afternoon sun in causing warm currents of air to rise along the brick wall with westerly exposure at the Pinckney Street location led to the removal of this instrument, and the Charlesbank instrument was shifted to the north end of the building. Fear of the modifying influence of the mass of masonry in the supporting walls at the University Club, Cambridge bridge and Riverbank Court locations led me to place these three instruments on tall isolated posts. Several series of observations with duplicate instruments were made, for determining the range of error due to such local influences.

It is probable that, when the sun was shining directly upon the outside of these wooden louvre boxes or shelters, the effect was to exaggerate the record curve slightly; for this is found to be the case with larger and thicker standard shelters of the Weather Bureau type used at the Blue Hill observatory. (See "Annals Harvard Observatory," vol. 20, part 1, Blue Hill Observations, 1887, p. 119.) To lessen this, we added a shade composed of a piece of house blind, painted nearly white, about four inches away from the south side of those of our shelters that were exposed on posts, as can be seen in some of the accompanying photographs.

With either the *Richard* or the *Draper* thermograph, the time required for the absorption of heat by the mass of the instrument causes it to lag a little behind the real temperature of the air.

However, it is the comparative temperature rather than the absolute temperature that we are seeking; and we have the safeguard, in this question of comparison, that these ten thermograph instruments were all precisely alike, and that they were all set in the same kind of shelter, and sooner or later in the course of the experiments all were subjected to very nearly the same conditions of exposure, and that their corrections were determined each week day by a standard mercurial thermometer.

Toward the close of our observations, as already stated on p. 484, maximum and minimum thermometers were also exposed continuously in each shelter, and read daily, for a further check, and were found to agree excellently with the thermograph temperature as corrected by the daily comparison with the mercurial.

Probable Degree of Precision of Measurement obtained. — From the facts that instruments and shelters were alike, and that occasional errors tend to balance, I am led to believe, after a careful study of the records, that the final mean values in our series of comparison of temperatures at various stations, reported on p. 476, do not contain an error so great as 1 degree F.

COMPARISON OF TEMPERATURES OF AIR AT DIFFERENT LEVELS OVER THE WATER AND UNDER DIFFERENT EXPOSURES IN SAME GENERAL LOCALITY.

The thermometer locations to be of the most practical value in our study should be representative of those locations at which the most persons would be found, — on the bridges, on the streets close to the basin, on roof garden twelve to twenty feet above the streets, like "The Deck" at University Club, or the second story fire-escape at the Institute of Technology, or five feet above the turf at the Cambridge parkway or "The Front." The temperature of the air down at a level close to the water as observed by Professor Porter did not appear to be of so much importance for the practical questions then under discussion.

To take continuous observations from a boat in mid-stream by self-recording instruments was impracticable, but it did seem of some importance to make a few comparisons between the temperature at different levels in the same vertical over the water.

Obviously, the brightness of the sun, the shelter and the force of the wind and the difference between temperatures of water and air will exercise a great influence over these differences of air temperature at different levels; a brisk wind will keep the air so thoroughly mixed that little difference can be found.

It requires a good deal of care to so locate and shelter a thermometer that its readings will accurately give the temperature of the air within 1 or 2 degrees, at all times, because of local air currents, occasional shadows as of trees, insolation, radiation to and from instrument and because of the effect of neighboring masses which absorb heat in the hours of sunshine and give it out at night at a different rate from the average surface of the ground.

A few observations were made on the variation in temperature under different exposures in the same general locality, but time failed for our making these as exhaustive as desired.

Perhaps the most interesting series was that of comparison between the temperature at a boat near the middle of basin near Harvard bridge with the tem-

perature in the thermograph shelter upon the adjacent drawbridge pier, also a comparison of the temperature at two exposures at same height but at positions upon the pier differing in respect to their exposure to the water.

These comparisons were made on a moderately warm day (September 23, 1.30 to 4 P.M.), when there was a cloudless sky, slight haze, moderately bright sun and almost no wind. Air was about 10.5 degrees F. warmer than water; water, 63.6 degrees; air in shelter, 74.1 degrees; tide nearly high, and coming in.

Our two best mercurial thermometers were used; these were graduated to tenths of degrees C., and read to hundredths by estimation, and the readings corrected for errors of graduation. Every obvious precaution was taken to ensure accuracy. A series of ten or more simultaneous readings was taken in each case, to make certain that instruments were in a settled condition.

First Comparison.— Thermometer in standard shelter *versus* thermometer in open air, shaded by umbrella, and held out over the water on shady side of wharf.

Instrument No. 9522, inside of the standard shelter, located the same as in the regular observations, attached to the north side of the small wooden shed upon west end of the long drawbridge pier, this pier consisting of a plank platform resting on piles. The shelter was in the shade of the shed, and back about eighteen feet from edge of platform. (See plan and photograph.)

Both thermometers were at a level about five feet above the platform, which was about eight feet above the tide-water level at that time; so both thermometers were about 13 feet above the water.

Instrument No. 9507 was held out over the water, in shade of umbrella, one foot beyond north edge of this pile and plank pier. About midway of the series of observations the positions of the two thermometers were exchanged.

A series of twenty observations showed that the thermometer 13 feet above the water, shaded from direct rays of sun, on shady side of wharf, stood 1.55 degrees F. lower than the thermometer at the same level, inside the shelter, shielded from radiation, and with a plank floor between the shelter and the water.

Second Comparison.— Exposure in a shelter above the plank platform of pier 13 feet above water level *versus* exposure at a boat nearer to the water level.

Three mercurial thermometers were used, one in shelter as before, two at boat anchored about one hundred feet west from pier. Time, about three-quarters hour later than first series; conditions of sun, wind and tide as before.

Of the two thermometers at boat, one was held one foot above surface of water; the other was held five feet above surface of water.

Both of these thermometers were shaded from direct rays of sun by an umbrella, and were exposed to the free air. Both hung out over water about five-tenths feet beyond edge of boat, and on the shady side of boat. Both hung in the same vertical.

The average of a series of fourteen excellent simultaneous observations showed, under these conditions of faint wind, with water 10.5 degrees cooler than air: —

(*a*) That at one foot above water, on shady side of boat, it was .48 degree F. cooler than at five feet above surface of water in same vertical.

(*b*) That at five feet above water, on shady side of boat, it was 3.54 degrees F. cooler than in the standard shelter five feet above the plank platform of the pier and thirteen feet above the water.

It is to be supposed that with more wind this difference would have been less, and that with same wind and the 20 degrees difference in temperature of air and water which sometimes occurs it would have been more.

Third Comparison.— At shady side of boat *versus* at sunny side of boat, both near to water.

Two thermometers, both one foot above water, both shaded from sun by umbrellas, one on sunny side of boat, receiving reflection of sun from water, the other on shady side of boat. Boat in middle of river about five hundred feet east from Harvard Bridge.

In a series of sixteen observations with our two most delicate thermometers, the temperature on shady side of boat one foot above water averaged 1.87 degrees F. cooler than on sunny side of boat at same distance above water.

At beginning of series, difference was about 2 degrees; then the haze thickened, sun appeared less bright, and the difference fell to about 1.5 degrees; it then brightened, and the difference rose to 2.4 degrees.

The above comparisons serve to show that *great care must be taken in exposing thermometers for measuring the temperature of the air over a body of water.* If water is much cooler than air, and wind is light, the temperature is materially lower within a foot or two of the water than it is 5 feet above.

It would have been very interesting to have carried these comparisons further, and under a variety of circumstances.

On a windy day or a cloudy day, probably much smaller differences than the above would have been found. This day was exceptional in its freedom from the wind that commonly prevails in summer all around this basin.

Exposure Differences, at University Club. — Another series of comparisons was made at the University Club, because of the change of the thermometer shelter from a location under an awning against a brick wall to a location on top of tall post about fifty feet nearer to the water. This latter shelter had a sunshade back and a double top. Bright sun, wind very light; surface of water in places showed almost no ripple.

At 9 A.M., with temperature rising 2.6 degrees per hour, our two best instruments showed for first half hour that it was 1.1 degrees F. cooler in the shelter attached to the brick wall. After this, a little more breeze springing up, the temperature rose more rapidly, and apparently the thermometer shelter on the tall post with the free all-around exposure responded more quickly than that close to the wall in the sheltered position, and for the next hour's observations it was found 2.1 degrees F. cooler at the shaded old location next to the brick house than at the new location where sun was shining directly on the outer shield of the shelter.

In the afternoon of same day another comparison was made, about 2 P.M., when temperature had nearly reached its maximum for day, and was changing slowly. The location in the shade under the awning next to the brick wall was found to be .3 degree F. warmer than in the shelter on top of tall post.

The experiment was then tried of holding an umbrella over the shelter on the post, to see if this extra shade affected the reading of thermometer. This shelter, it will be remembered, had already been provided with a double top and a shade made from a house blind, about four inches away from its southerly side.

The umbrella was kept there half an hour and then removed, meanwhile observing both thermometers. There happened to be some oscillation of temperature going on at this time, but it was found that the effect of thus shading the shelter by the umbrella was either inappreciable or less than .2 degree F.

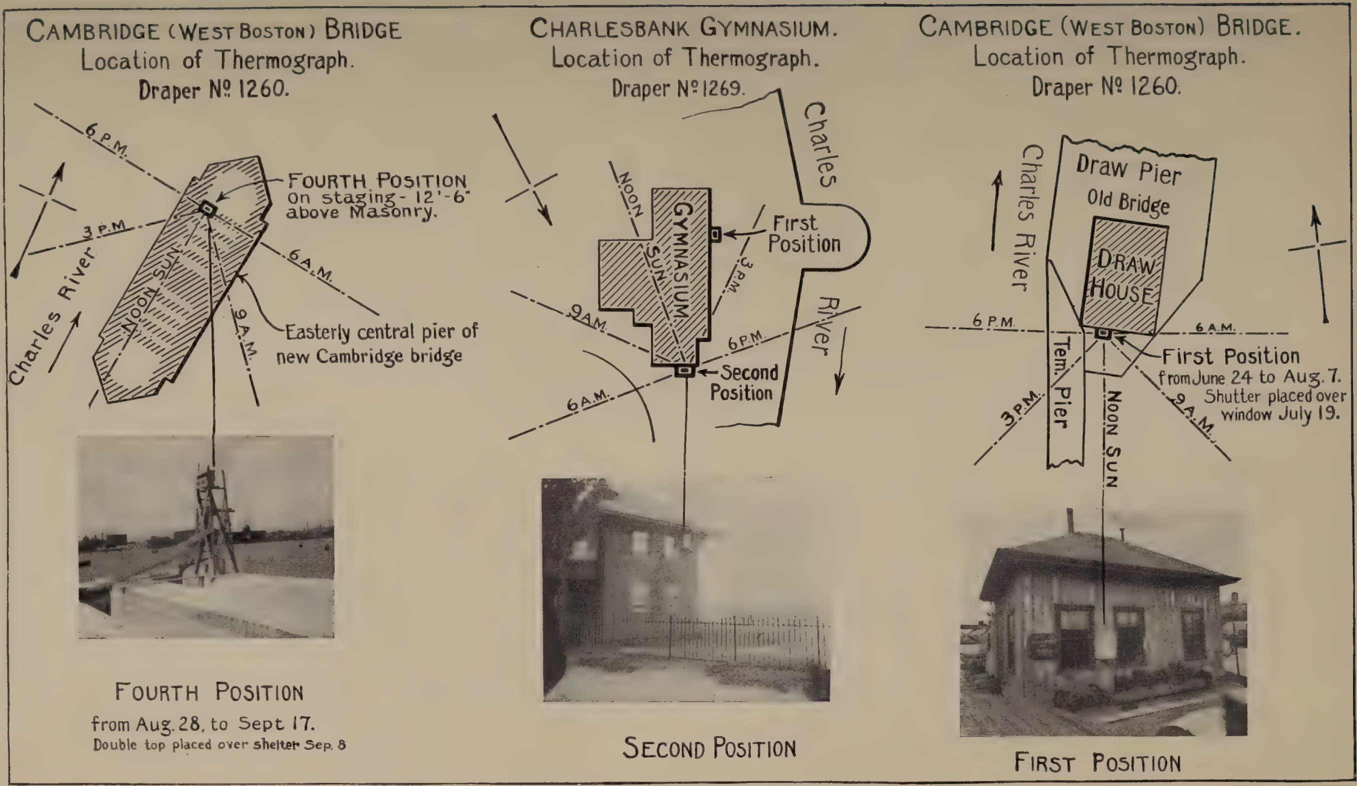
Later, at 5.10 to 5.50 P.M. of same day, a third comparison was made after sun had got around so as to shine on the face of building to which shelter had been formerly attached, and was shining upon the wooden platform not far away from it. The portable shelter, the wall and the floor in its immediate vicinity were shaded by the awning. Temperature was falling at a rate of about 2.5 degrees per hour.

The thermometer in temporary shelter against the wall showed it 1.5 degrees F. warmer at that locality than out in the shelter on top of the post, where there was a light breeze.

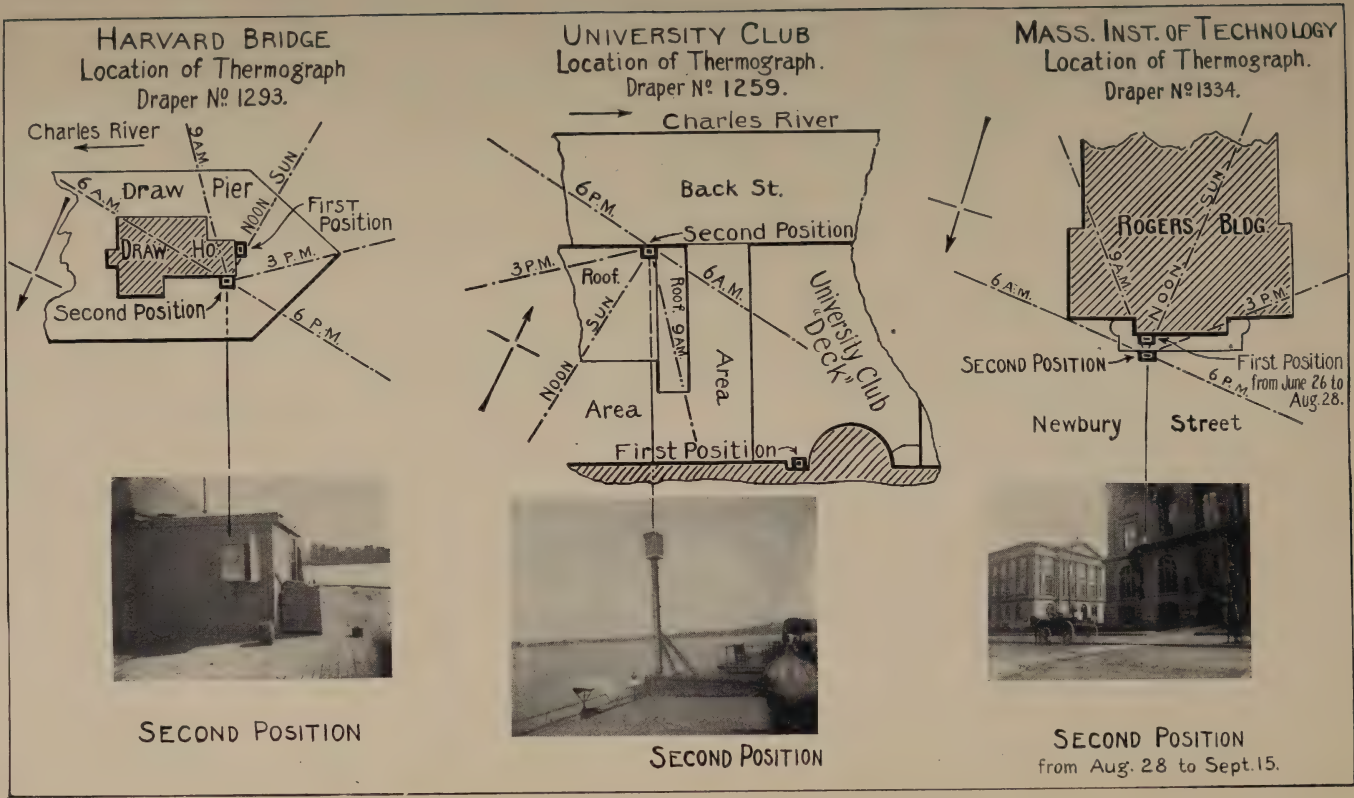
The teaching of this plainly is: *avoid locating thermometers for precise work in nooks out of the wind, and avoid attachment to brick walls, notwithstanding these walls are shaded in the immediate vicinity of the thermometer.*

This day's observation at the University Club showed that the old location on the wall was 1.1 degree cooler in the morning, .3 degree warmer at 2 P.M., and 1.5 degrees warmer late in the afternoon, with conditions of bright sunshine and very faint wind. Under ordinary conditions, with a fresh wind, the differences would probably have been much less.

Exposure Differences at Cambridge Bridge. — At the Cambridge bridge thermograph station a change in location of the shelter had been made to a greater height above the stone pier, because of fearing some disturbing influence in the temperature shown from proximity of thermograph to this mass of masonry. The old location of the shelter was about five feet above mean high water, the



Location of Shelters for Self-recording Thermometers.



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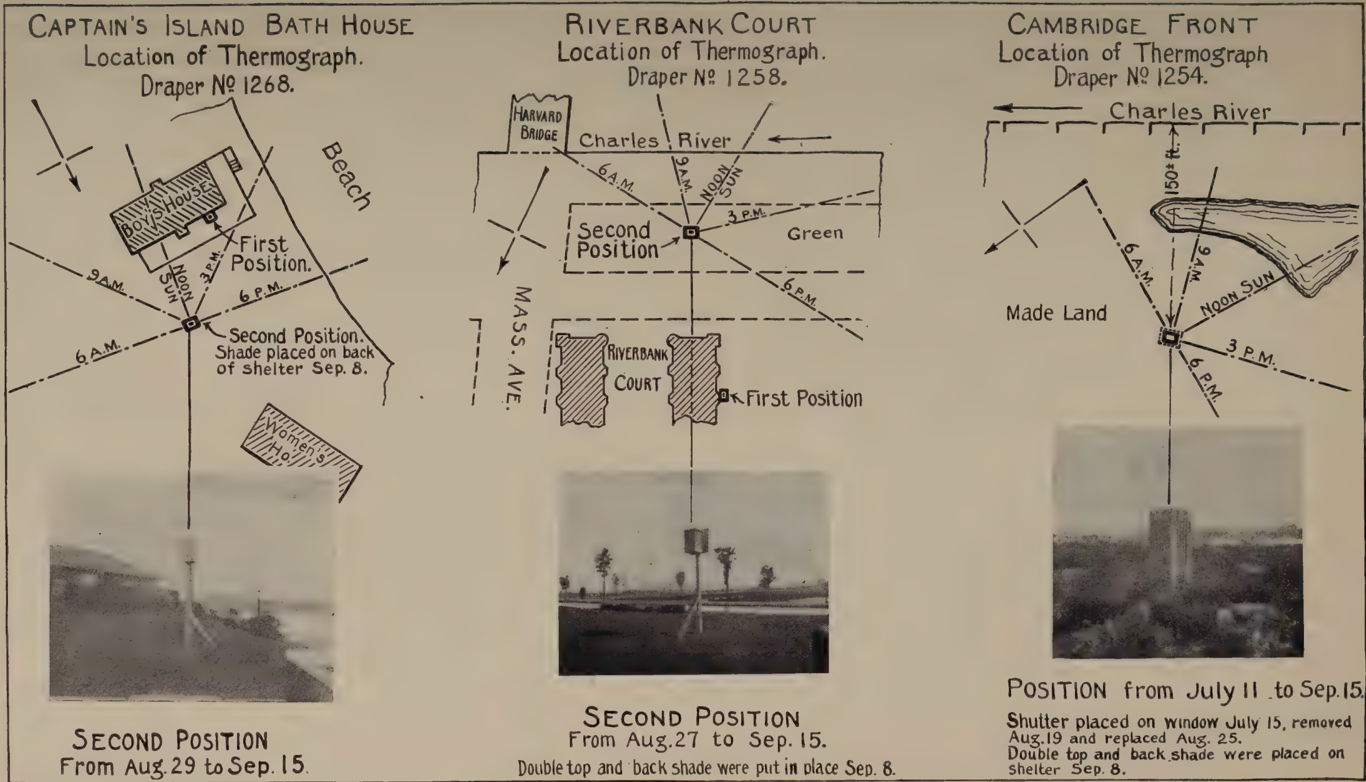
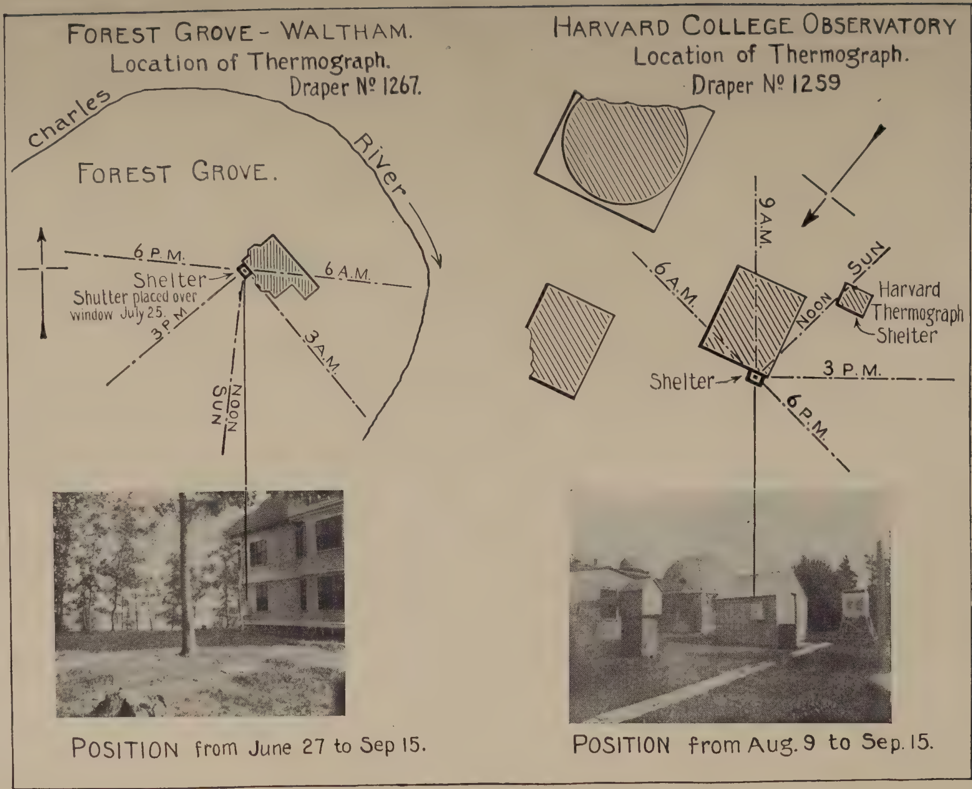


Location of Shelters for Self-recording Thermometers.



Location of Shelters for Self-recording Thermometers.

shelter being attached directly to the north end of masonry pier, with centre about two feet below its top, and a two-inch space between its back and the stone. The new location was on top of a tall post about fifteen feet higher and about twenty feet above level of mean high water. (See photograph.)

At from 2.05 to 2.55 P.M., September 12, with bright sun most of the time, moderate wind from south, tide rising and one-third in, and with portable shelter in old position shaded from sun by the masonry and shielded by pier from the wind, eleven simultaneous observations, five minutes apart, showed changing conditions in old position, due perhaps to stray slants of wind of lower temperature in the eddy, but tending to 1.5 degrees cooler at the old location under the existing conditions.

At 3.03 to 3.23 P.M., with the portable shelter seven and five-tenths feet directly below regular shelter on top of post, both shelters in exactly same condition of exposure to sun and wind, it was found by best mercurial thermometers to be .13 degree cooler at the lower position.

Temperature of water 69.8 degrees and of air 74.5 degrees, and wind moderate from the south-west.

At 3.35 to 3.51 P.M., with portable shelter, four feet below regular shelter, the thermometer in it averaged reading 0.3 degree cooler than in the regular shelter, or practically the same.

At from 4.10 to 4.40 P.M., temperature now falling about 2.5 degrees per hour, portable shelter was moved to south end of pier, to bring it into the wind and up stream from influence of pier on its temperature. It was set about four feet lower than the permanent shelter, thirteen feet above the water. Both shelters fully exposed to sun and wind, thirty minutes observation showed a temperature .51 degree F. cooler in this position of the portable shelter.

At from 4.55 to 5.15 P.M., portable shelter moved to a beam projecting from south-west corner of pier, and at nine feet lower elevation than just before, or about five feet above water.

Five simultaneous observations at five minute intervals averaged .25 degree F. cooler at this position than in the permanent shelter.

In this day's work, frequent little variations of one-quarter to one-half degree were noted, with no other apparent cause than the shifting air currents from the cooler water beneath.

Comparisons of Air Temperature in Adjacent Positions by Means of Thermophone. — At the University Club location a series of temperatures was observed with a thermophone in comparison with standard thermometer in the shelter, at the "new location," on top of post, twenty-four feet above ground. The thermophone was suspended at various heights, as nearly as possible in the same vertical, and protected from radiation by the small portable shelter, with the following result: —

	Corrected Reading of Mercurial Thermometer in Regular Shelter, Twenty-four Feet above Ground.	Distance of Thermophone below the Thermometer (Feet).	Comparative Temperatures (Degrees F.).
	69.29	2.5	.19 warmer at thermophone.
	69.05	5.0	.76 " "
	69.13	7.5	1.30 " "
	69.92	9.5	1.38 " "
Nearing shed roof, . .	67.06*	13.9	1.53 " "
At top of fence, . .	66.85	15.7	1.90 " "
About three feet from wall, in sun, . . .	66.70	18.0	3.52 " "
In enclosed yard, over brick pavement, . .	66.75	23.0	4.36 " "

* Wind changing to northerly.

Unfortunately, the observer did not occasionally return to the original comparisons with instruments side by side and thus preclude the chance of periodic error. The thermophone shelter was much smaller than the regular shelter, and possibly was a shade darker in color. It had been exposed to sun, with thermophone inside it, for three-quarters of an hour before beginning these comparisons.

Some further thermophone comparisons were attempted at Cambridge bridge, at various distances above water; but the results were anomalous, perhaps due to some trouble with the electrical connections. No time was found in which to investigate this further.

These experiments serve to show that, for accurate work, care must be taken to place a thermometer shelter where it will receive the faint air currents freely, and where it will be at a safe distance from brick buildings or brick walls, which may retain some of the coolness of night well into the day; and that the thermometer must not be placed near walls in sheltered nooks which receive the direct rays of sun, or in angles or eddies which are so shut in that the wind does not quickly dissipate the heat absorbed by the surroundings.

As already stated on p. 475, and as shown in the table on p. 476, this long series of careful observations at twenty different locations about the Charles basin prove conclusively that the present influx of sea water twice daily does not lower the temperature of the air immediately around the shores of the basin by more than about a single degree Fahrenheit, *and the building of the proposed dam will make no noteworthy change.*

JOHN R. FREEMAN.

Appendix No. 18.

Notes on Conditions producing Maximum Height in Proposed Charles River Basin.

By John R. Freeman, C.E.

Notes on Extreme Tides and Extreme Rainfalls.

In order to make sure that the sluiceway area through the dam provided for in the designs submitted would meet the most extreme conditions of flood and tide, and, on the other hand, to make sure that the amount of sluiceway proposed was not extravagant, I have tried, without much success, to collect notes that would show the possibility or the degree of probability of an extremely heavy rainfall occurring at the same time as an extremely high tide, — in other words, the possibility that a "Stony Brook flood" might be superimposed upon a "Minot's Ledge tide."

The Stony Brook flood occurred Feb. 12, 1886, and, although we have no tide-gauge reading on that date, no record has been found showing that the tide reached an excessive height at that time.

The Minot's Ledge light-house was destroyed in the great gale of April 16, 1851, at which time occurred the highest tide ever yet recorded in Boston harbor, — probably the highest for at least one hundred and twenty-five years; but we have no record that any great freshet occurred at the same time, and the probability of two such infrequent events as a flood of this magnitude and a tide of this height occurring simultaneously is extremely small.*

The records of floods and tides are not complete enough to establish the impossibility of a very heavy flood being superimposed upon a very high tide. They show that the highest tides have been accompanied by heavy rain; although, so far as observed, not one of these extremely high tides has been accompanied by the conditions necessary for a flood of anywhere near the height of that of February, 1886, or any of the other noted floods.†

The twelve highest tides observed during the twenty-nine years of continuous tidal observations for the United States Coast Survey from 1847 to 1876, at Charlestown Navy Yard, were as follows: —

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* It was thought that a study of the records might perhaps show that the extreme freshet came only with a wind from the south or from a quarter different from that necessary to produce the very highest tides, or that the melting of snow, or heavy rainfall on frozen ground, might be essential to the greatest flood.

Unfortunately for this comparison, during the long series of tidal observations by the Coast Survey, which began in 1847 and were discontinued in 1876, we have no such exact observations on strength of wind or rate of rainfall as are now taken by the United States Weather Bureau; but the chief of the Weather Bureau, Prof. Willis L. Moore, has furnished such information as is on file. The superintendent of the Coast Survey furnished the information regarding tides on which the tables on the following pages are based.

† Flood records on the Charles prior to about 1876 are meagre. Some very valuable information in connection with the rain gauge is on file at the Boston Manufacturing Company's cotton factory in Waltham.

[Elevations given are above "Boston base."]

DATE.	Time of High Water.	Observed Height of High Water.	Excess over Predicted Height of High Water.	Raising of Low Water at Tides next Preceding and Following.	Predicted Range from this High Water to Mean of Nearest Two Low Waters.	Excess of Actual Range over Predicted Range.	Wind and Rainfall.
	H. M.	Feet.	Feet.	Feet.	Feet.	Feet.	
1847, Sept. 24, .	12 49	15.24	4.5	−0.6 −0.4	10.5	5.0	Wind north-east fresh for forty-eight hours before highest water; also raining hard.
1851, March 18, .	12 02	14.54	3.7	0.0 −0.8	10.7	4.2	Wind north-east fresh for sixty hours before maximum high water; snowy.
1851, April 15, .	23 30	14.94	3.0	+1.0 +1.0	11.0	2.9	
1851, April 16,	12 –	15.67	4.8	1.0 2.4	11.0	3.0	North-east gale blowing thirty-six hours before highest water and raining hard part of time. Minot's light-house destroyed on 17th.
1851, April 17, .	– 42	14.34	3.5	+2.4 0.3	10.8	2.2	
1853, Dec. 29, .	10 26	14.39	3.4	−0.8 0.5	11.1	3.6	Northerly gale with snow began ten hours before high water.
1854, Dec. 3, .	23 10	14.29	3.3	−0.6 0.9	11.1	3.2	Easterly gale with rain began eight hours before high water.
1857, Dec. 31, .	11 18	13.86	3.0	−0.6 −1.2	11.0	3.9	Fresh south-west wind began eighteen hours before high water.
1861, Nov. 2, .	11 54	14.24	3.3	−0.8 +1.4	11.0	3.0	Strong easterly gale, with rain, for forty hours before maximum high water.
1867, Dec. 13, .	12 55	14.11	3.3	– −1.7	10.5	5.0	
1868, Feb. 9, .	12 –	14.49	3.4	−0.8 −1.4	11.0	4.5	
1871, Nov. 15, .	13 33	14.14	2.4	+1.1 −0.2	11.0	2.0	Strong easterly wind, seventeen miles per hour, on previous day, twenty-eight miles per hour on day of storm; rainfall, three inches; wind began to abate two hours before high water.

In the preceding table of high tides it is interesting to note that with a single exception *every one of these extreme tides occurred at about noon and all under spring tide conditions*, with a normal rise and fall of about 11 feet.

It is rather surprising to note that in a majority of these examples *the strong easterly wind did not raise the low-water level at all*, the whole increase in tidal range in those cases being found in the pushing up of the high tide.

Somewhat similarly, in the table on the following page, the extreme low waters are nearly all found to occur at about 6 o'clock, and mostly in the morning, this obviously following from the relative position of sun and moon requisite for spring tide effects. Here, too, the depression of the high-water elevation by the westerly wind is less than the depression of the low-water elevation.

These extreme variations to which the tidal heights may be modified by long-continued winds, barometric waves and other causes, perhaps serve to make one cautious about accepting reported changes of depth over ledges based on a single measurement until it is certain that the observer was trained in methods of precise observations, that all the attendant circumstances were noted, and that he has given proof of proper caution about taking short-term averages without special attention to barometer and to winds long continued from one direction.

It appears probable that only three times in the past one hundred and thirty years (in 1830, 1847 and 1851) has high tide risen above grade 15.0, Boston base, or risen high enough to overtop the walls of the dry dock. In 1898 it came almost to this height.

The most severe conditions of tide for holding back the outflow from the sluices in the proposed dam, and thereby tending to raise the water level in the basin, so far as I have found by record or tradition, are found in the extremely high "low water" in the great storm of Nov. 27, 1898, in which the steamer "Portland" was lost, and during which, according to the Metropolitan Sewerage Commission's recording tide gauge at Deer Island, the heights were, by Boston base: —

	Predicted.	Actual.	Excess.
4.18 A.M.,	+0.4 feet.	5.4 feet.	5.0 feet.
10.29 A.M.,	+10.2 feet.	14.6 feet.	4.4 feet.
4.55 P.M.,	−0.4 feet.	–	–
11.07 P.M.,	+8.7 feet.	–	–

This is a low run of tides, considering this period was at the full of the moon.

Twelve and one-half inches of snow fell in this storm, which is equal to 1.1 inches of rain; but this caused no immediate freshet in the Charles.

This is the tide used by Professor Porter, combined with a flood of 7,000 cubic feet per second, as basis of his diagram on p. 404 of evidence.

Never before or since, so far as I have been able to learn, has the wind forced the tide to so great an excess above the predicted height. This tide was accompanied by no freshet in the Charles, but *in computing the capacity of sluiceways and in estimating the height to which the basin level might be raised, I have assumed that a tide like this most extraordinary one of Nov.* 27, 1898, *might possibly be surmounted by a freshet of about* 50 *per cent. larger volume than the greatest on record, and find extreme height necessary inside the basin only* 11.7 *feet, or but little above the present extreme spring tides.*

The twelve lowest tides observed in Boston harbor during the twenty-nine years of United States Coast Survey observations, at Charlestown Navy Yard, were as follows: —

DATE.	Time of Low Water.	Observed Height of Low Water below Boston Base.	Lower than Predicted.	Depression of High Water at Tides next Preceding and Following.	Predicted Range from this Low Water to Mean of Preceding and Following High Water.	Excess of Actual Range over Predicted Range.	Wind and Rainfall.
	H. M.	Feet.	Feet.	Feet.	Feet.	Feet.	
1848, March 6, .	18 09	—2.31	2.4	—0.7 / —0.6	10.7	3.0	Wind north-west, very fresh for forty-eight hours before low water, and fair.
1851, Feb. 16, .	17 33	—2.33	2.3	—1.3 / —0.8	10.8	3.3	Wind south-west, fresh for two days before low water, and fair.
1854, Jan. 28, .	17 10	—2.40	2.3	—0.0 / +0.4	11.1	2.1	Wind west, fresh for twenty hours before low water, and fair.
1856, March 8, .	+8 33	—2.38	2.7	—1.6 / —0.7	10.3	3.9	Wind south-east, fresh for twenty-one hours before low water, and rain.
1861, March 28, .	6 33	—2.70	2.9	—1.7 / —0.2	10.5	3.9	Wind west, fresh for twenty-six hours before low water, and rain.
1862, April 16, .	6 28	—2.30	2.5	—0.9 / +0.6	10.5	3.0	Wind south-west, fresh for thirty-two hours before low water, and fair.
1862, Nov. 23, .	18 55	—2.56	2.9	—1.1 / +0.6	10.4	3.1	Wind north, fresh for thirteen hours before low water, and fair.
1864, Feb. 9, .	18 45	—2.60	2.9	—0.2 / +0.3	10.4	2.8	Wind west, fresh for two days before low water, and fair.
1864, Dec. 12, .	16 49	—2.30	2.1	+0.2 / 0.0	11.2	2.0	Wind west, fresh for thirteen hours before low water, and fair.
1866, Feb. 16, .	18 21	—2.26	2.4	+0.6 / +1.0	10.6	1.7	Wind west, fresh for thirty-eight hours before low water, and fair.
1869, Feb. 27, .	18 12	—2.73	2.9	—1.0 / —0.1	10.6	3.3	
1874, Feb. 18, .	18 46	—2.20	2.6	—1.2 / —1.0	10.2	3.7	Wind north-west, fresh.

CONDITIONS OF WIND OBSERVED IN SOME OF THE HEAVIEST RAINFALLS.

In the storm that produced the "Stony Brook flood," rain began Feb. 11, 1886, at 7.45 A.M., continued until February 13, at 2.45, and the total precipitation was 5.62 inches.

The wind was east to north-east, blowing a gale, from 2.30 P.M. to 9.45 P.M. of February 11; maximum velocity, 28 miles. Six or seven inches of snow on ground at beginning added materially to flood. On February 12, A.M., wind north-east, velocity 12 miles per hour; afternoon wind shifted to north-west, light; evening wind west, 7 miles.

This wind thus appears not to have continued long enough from the eastward to produce a noteworthy effect on the tide.

Since the establishment of the weather observation station at Boston in 1870, there have been two storms with greater rainfall than that of February, 1886, which produced the Stony Brook flood, and one with a slightly less rainfall occurring in a shorter period. These were as follows: —

June 9 and 10, 1875, a total of 5.37 inches of rain fell, of which nearly the whole fell inside of twenty-four hours. Sewers were not capable of carrying it away, and many cellars were flooded.

June 9, A.M., wind easterly, velocity, ...	4 miles per hour.
June 9, P.M., wind north-east, velocity, ...	10 miles per hour.
June 9, night, wind east, velocity, ...	9 miles per hour.
June 10, morning, wind north, velocity, ...	7 miles per hour.
June 10, afternoon, wind north-west, velocity, . . .	3 miles per hour.

Obviously this wind was not strong enough to seriously affect the tide.

Nov. 20–22, 1876, a total of 6.37 inches of rain fell, nearly all in the first two days.

November 19, wind began at 1 P.M.; at night was 25 miles per hour from east.
November 20, P.M., wind became severe, reaching 50 miles per hour at 6 20 P.M.
November 20, at night, wind decreased to 33 miles per hour.
November 21, wind decreasing, backing to north; heavy wind ended at 4 P.M.

This wind was severe, and from the east, but did not blow long enough to produce a maximum effect on the tide.

Aug. 16–19, 1879, a total of 6.25 inches of rain fell, of which 4.99 inches fell between 7.30 A.M. and 3.45 P.M. of the 19th.

August 16, wind light to brisk from the north to the south-east.
August 17, wind north-east; light to fresh all day.
August 18, at 7.30 P.M., high wind set in from north-east, and by 11 P.M. reached a heavy gale, averaging about 36 miles per hour from 8 to 12 P.M.
August 19, wind continued to blow a gale from north-east until 12.30 A.M., then became calm for thirty minutes, then came from the west and north-west with increased force for several hours.

Obviously this wind was not one likely to affect the height of tide seriously.

For the heavy rainfall of June 9 and 10, 1875, we have not been able to obtain notes of flow in Charles River.

For the storm of Nov. 20–22, 1876, the water began to flow over the dam of the Boston Manufacturing Company at Waltham at noon of the 20th, attained a depth of 5 inches at midnight of the 20th, 8 inches at noon of the 21st, 10 inches at midnight, and remained at about this depth until the 24th, and ranged between 7 and 8 inches on the 25th, four days after the storm was practically over, thus showing the moderate and long-continued character of the freshets on the Charles.

In the heavy rainfall of Aug. 16–19, 1879, the water did not begin to flow over the Boston Manufacturing Company's dam until about noon of the 19th, at midnight had reached a depth of only 4.3 inches, and remained at from 2.1 to 4.3 inches flowing over for the next four days, — a very gentle freshet.

The foregoing notes all tend to show: —

(1) Tides high enough to seriously impede the discharge from the proposed basin are very rare.

(2) While heavy rains are commonly accompanied by easterly winds, rainfalls heavy enough to cause a freshet have seldom or never, so far as observed, been preceded by a long-continued wind sufficiently strong to produce extremely high tides.

(3) The Charles River is slow to respond to heavy rains, and the floods on it are not severe.

Appendix No. 19.

Estimate of Cost of Dam, Marginal Conduits and Embankment Walls.

By John R. Freeman, C.E.
Revised March, 1903.

By conversation with many persons interested in the proposed Charles River dam, I have found that it is not generally appreciated how fully the engineers of the Joint Board of 1894 studied out the details of the proposed structures, or how complete were their estimates of cost. It appeared unnecessary for me to duplicate their work.

Moreover, my time and that of my assistants was so fully occupied, up to the date fixed by law for the handing in of the committee's report, by matters connected with studies of pollution of the basin and the various possible remedies, together with the investigation of matters relative to the effect of the proposed dam on the harbor, that I was able to give but little time to the design of the dam itself. A brief study suffices to convince one of its feasibility, and the plans of the Joint Board, although not intended for a finality, appeared to serve the purpose of demonstrating the feasibility and estimating the cost with tolerable accuracy.

With the consent of Dr. H. P. Walcott, chairman of the State Board of Health, I have had the principal plans relative to the dam and the lock, that were made under the supervision of Mr. F. P. Stearns, chief engineer to the Joint Board of 1894, photo-engraved on a much smaller scale than the originals, and they are appended hereto.

Mr. Goodnough, chief engineer of the State Board of Health, who was himself employed upon these estimates of 1894, has very kindly copied off from their records the abstracts of their estimates of cost presented in the following table.

It is possible that some little readjustments of quantities were made on the final revision of these estimates, but it will be noted that the total is the same as that presented in the final report of the estimate of the chief engineer of the Joint Board, namely, $660,000 for dam and lock complete with all accessories except drawbridge and street pavements and fences.

The prices of labor, structural steel and of sundry building materials are considerably higher to-day than they were in 1894. The price of cement and some other important materials is no greater or even less than at that time. Improvements have been made in dredging and in pile driving which decrease the labor cost. Piles, cement, gravel and puddle from the river bed, water-borne stone from the Rockport or other quarries, and broken stone for concrete and wall backing, are the principal raw materials required. The great development in the construction of macadam roads has increased the facilities for obtaining the broken stone. As a whole, after reviewing the unit prices of the estimate of 1894, it appears that an addition of 10 per cent. should cover

the advance in prices. This, added to the $660,000 estimated by the Joint Board, would make the cost $726,000, at the present prices, for dam and sluices complete, according to the plans which follow.

PRELIMINARY COMPARISON OF COST OF COMBINED DAM AND BRIDGE WITH COST OF A NEW CRAIGIE BRIDGE WITHOUT ANY DAM.

First Comparison. — The engineer of the Joint Board of 1894 estimated that a dam 100 feet in width, located 600 feet above Craigie bridge, complete with lock and sluices, would cost $660,000. Adding 10 per cent. for increased prices, this becomes $726,000.

The cheapest of the approximate estimates prepared by the city engineer of Boston, Dec. 19, 1902, for rebuilding Craigie bridge 70 feet in width at grade 23, exclusive of grade damages, was $814,430.

While this figure for the bridge is more than for the dam, these estimates are not strictly comparable, and require adjustment to allow for differences of width, height and location of dam, etc., which are approximately as follows: —

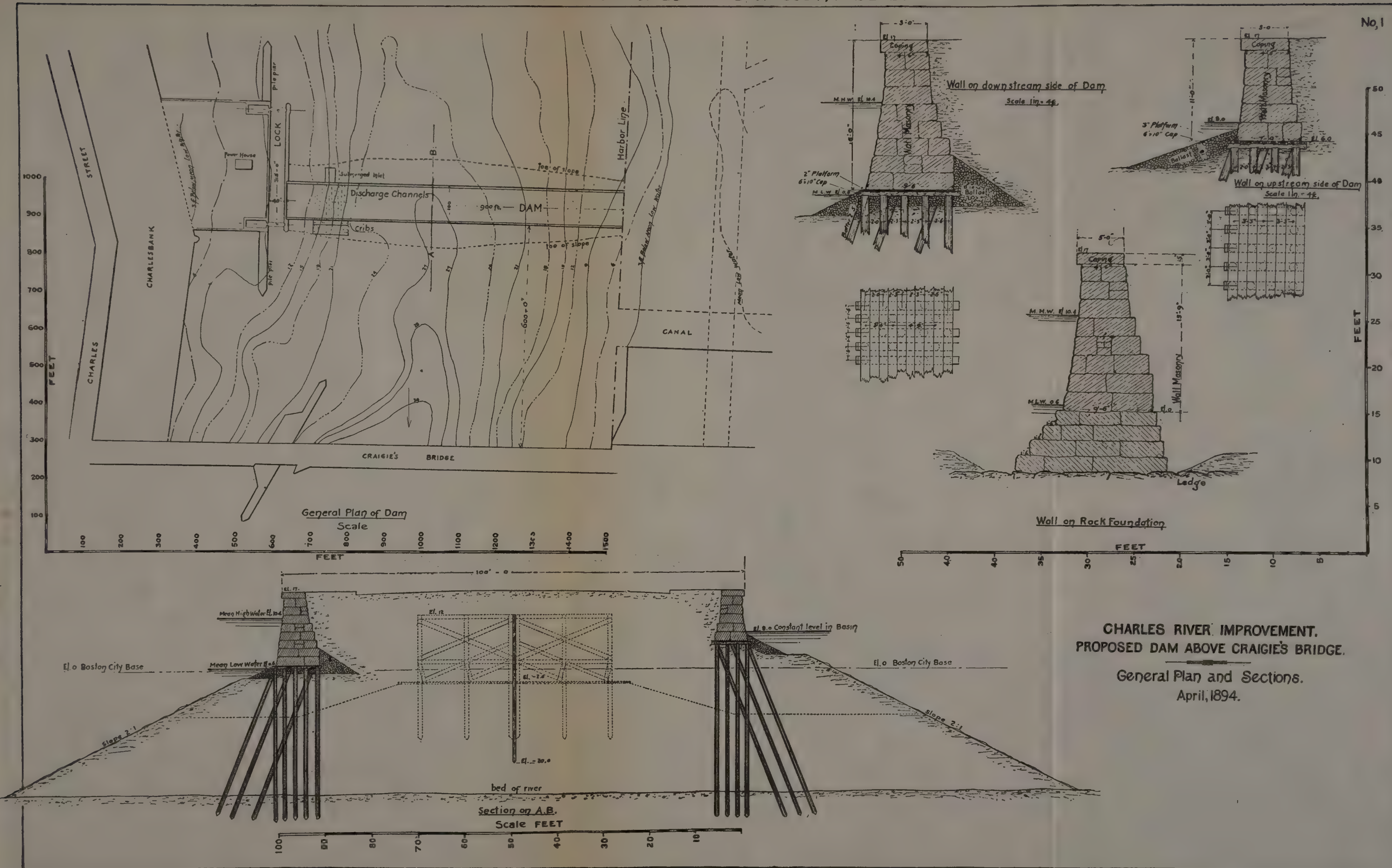
For the complete structure, dam, locks and sluices, shown in sheets 1 to 5 of preliminary drawings of 1894, 100 feet wide, grade 17: —	
Estimate of engineer of Joint Board in 1894 was $660,000; adding 10 per cent. for increase in cost of labor, etc., in 1902,	$726,000
Add for retractile draw, 50 feet span, 100 feet wide, about,	53,000
(Summer Street draw (50 by 100) over Fort Point Channel said to have cost $48,969, exclusive of engineering and inspection.)	
Add for 100 feet in length extra masonry and filling, due extra length at Craigie site (9 per cent. of $220,000), about,	20,000
Add for 18,000 cubic yards of extra filling, due greater depth of natural bottom at Craigie site,	9,000
Add for granite paving, concrete base, 10,000 square yards, at $4; asphalt sidewalks, 3,000 square yards, at $2.50,	47,500
Add for fences, 2,500 lineal feet, at $3, $7,500; drawbridge gates, $2,000,	9,500
Add for extra wall and filling and wall due slope from 17-22 near Cambridge end, to connect with present street grade, say,	5,000
Cost of "Joint Board dam" if built at Craigie site, with drawbridge and street surfacing and fencing added,	$870,0.

The bridge estimate most nearly comparable with this is the Bosto city engineer's plan No. 2, Appendix No. 13, p. 429. This is also for 100 feet in width and with a 50-foot draw, but its height on Boston end is raised 6 feet above present street grade and made 2 feet higher at draw, thus giving 8 feet head room at mean high water.

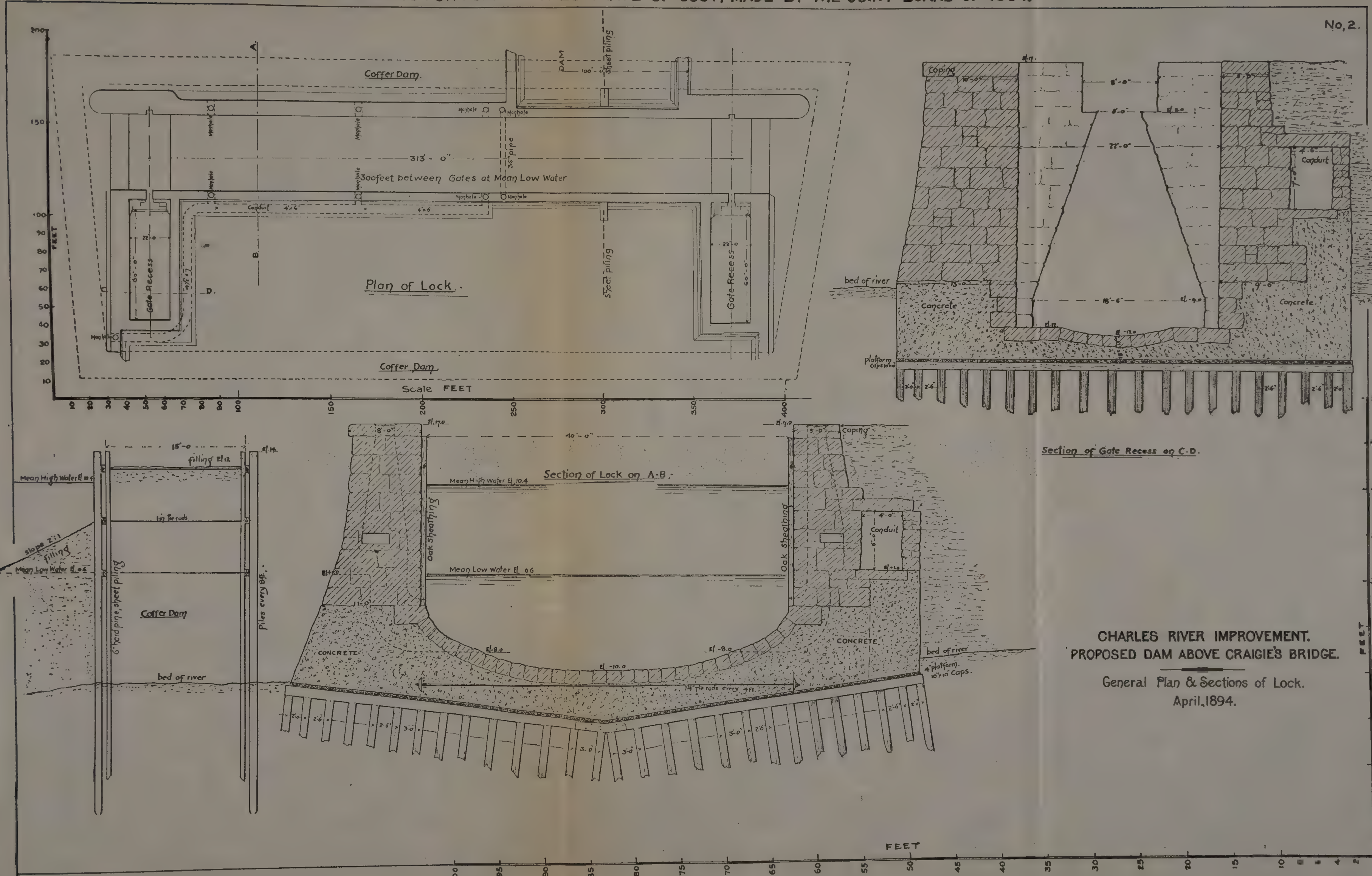
Exclusive of grade damages, the cost of this bridge is estimated by Mr. Jackson at,	$1,092,458
If the dam as above is raised to same grade, the extra cost would be: —	
Increase in wall masonry, about 2 yards by 3 yards by 460 yards by 2, equal to 5,520 cubic yards, at $12,	$66,240
Increase in earth filling, 2 yards by 30 yards by 400 yards, equal to 24,000 cubic yards, at $0.50,	12,000
	$78,240
Approaches as estimated by city engineer of Boston, $50,410, plus 15 per cent.,	57,971
Total increase due raising from grade 17+ to 23+,	$136,211
Add to cost of dam, lock, draw and roadway as above,	870,000
Total for dam, etc., strictly comparable with bridge,	$1,006,211

Which is $86,000 less for the dam and bridge combined than the estimate for bridge alone. Moreover, the cost of continually repainting the steel bridges, with possibly a small contribution to a sinking fund for its ultimate renewal when weakened by rust will, if capitalized, make the comparison still more favorable to the dam. Therefore it appears we may prudently state that the dam, lock and bridge combined will cost little if any more than the bridge alone.

PRELIMINARY DRAWINGS FOR PURPOSE OF ESTIMATE OF COST, MADE BY THE JOINT BOARD OF 1894.

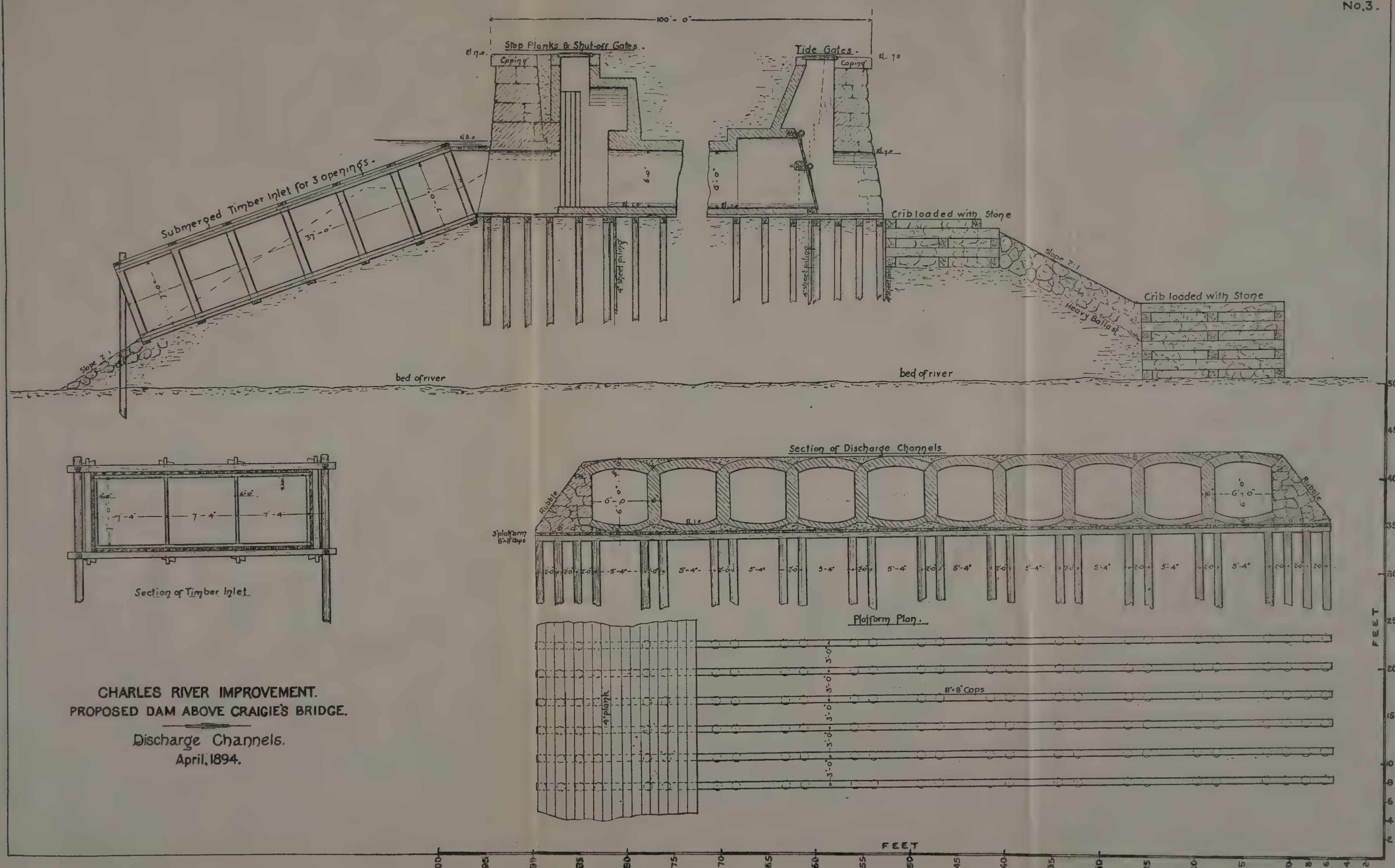


PRELIMINARY DRAWINGS FOR PURPOSE OF ESTIMATE OF COST, MADE BY THE JOINT BOARD OF 1894.



PRELIMINARY DRAWINGS FOR PURPOSE OF ESTIMATE OF COST, MADE BY THE JOINT BOARD OF 1894.

No. 3.

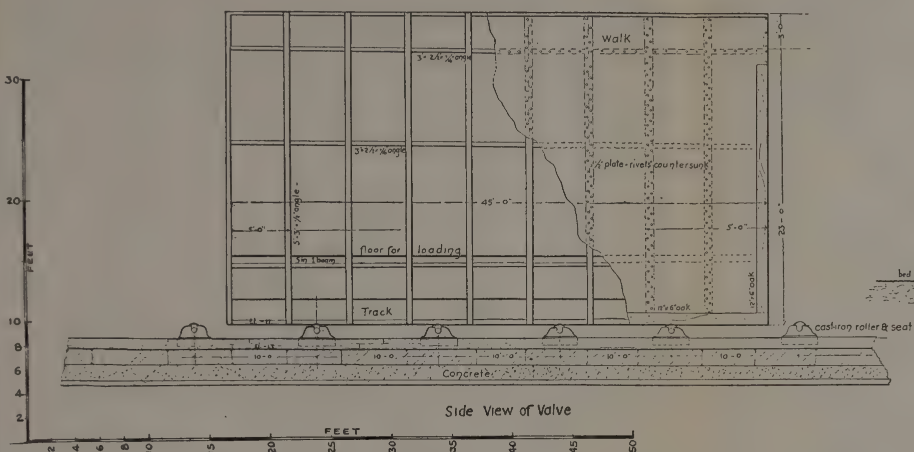


CHARLES RIVER IMPROVEMENT.
PROPOSED DAM ABOVE CRAIGIE'S BRIDGE.

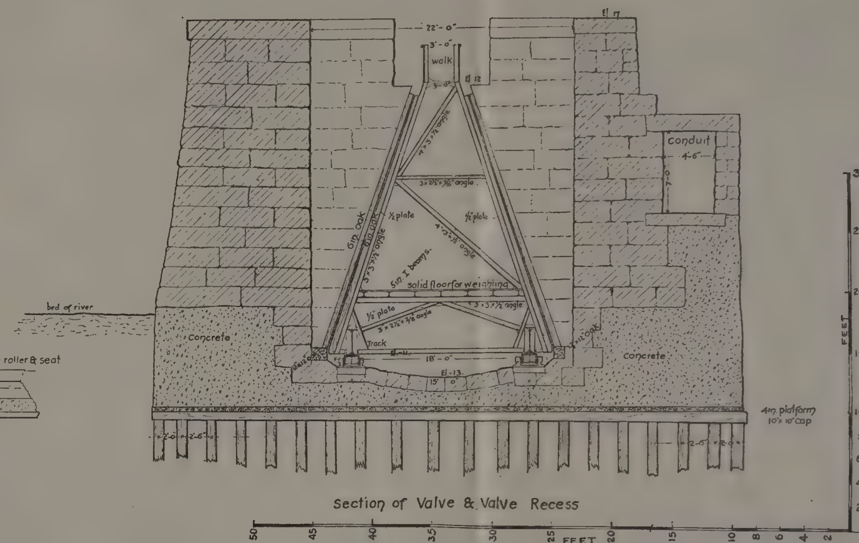
Discharge Channels.
April, 1894.

PRELIMINARY DRAWINGS FOR PURPOSE OF ESTIMATE OF COST, MADE BY THE JOINT BOARD OF 1894.

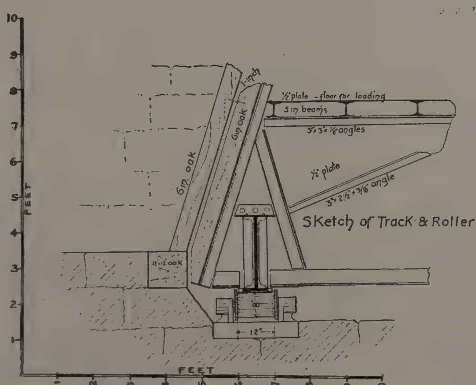
No. 4



Side View of Valve



Section of Valve & Valve Recess



SKetch of TracK & Roller

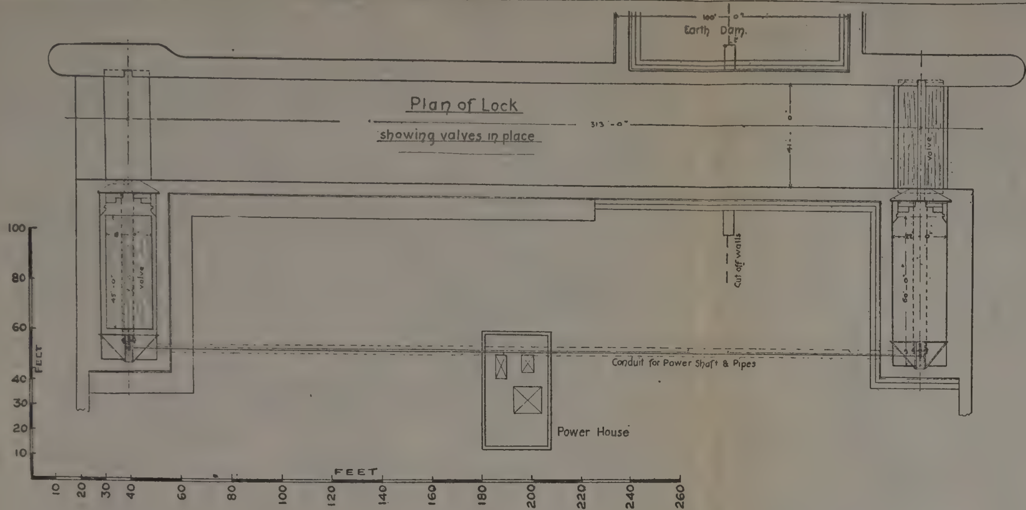
Note -
The Sketches of Valve and Power House [Plans No. 4 & 5] are the results of a study carried only far enough to determine the feasibility and approximate cost. No attempt has been made to show any of the suggested plans for tightening the valve when closed. -

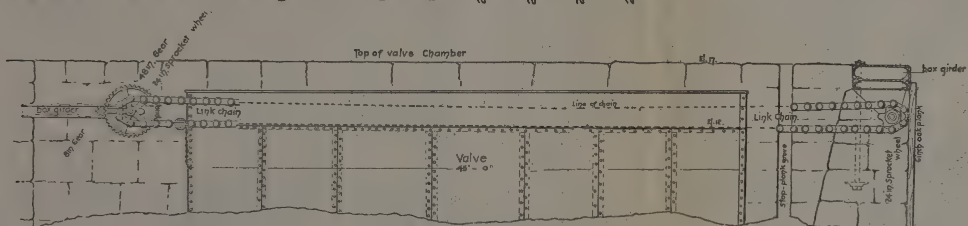
CHARLES RIVER IMPROVEMENT.
PROPOSED DAM ABOVE CRAIGIE'S BRIDGE.

Sketches of Lock Valves.
April, 1894.

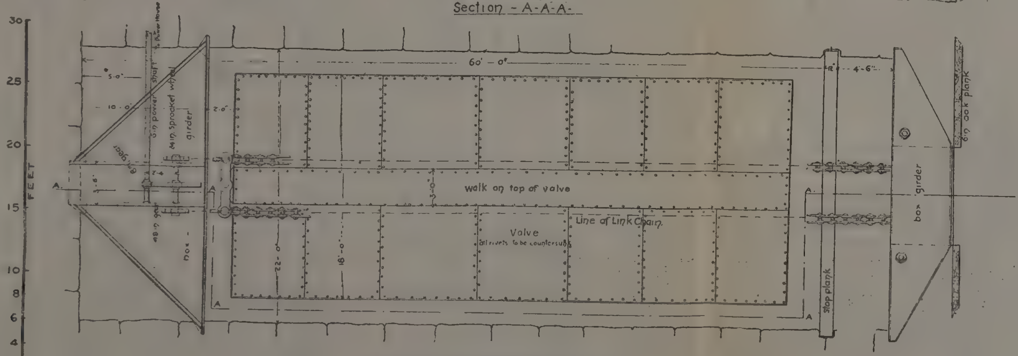
PRELIMINARY DRAWINGS FOR PURPOSE OF ESTIMATE OF COST, MADE BY THE JOINT BOARD OF 1894.

No. 5.

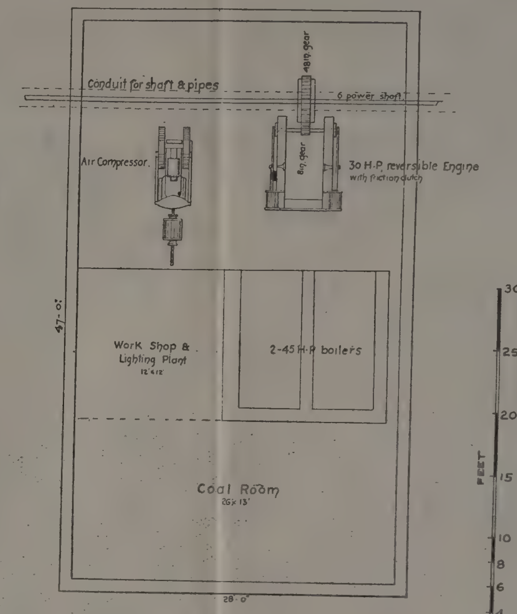




Section - A-A-A-



Plan of Valve Chamber - with valve.



Details of Power House

CHARLES RIVER IMPROVEMENT.

PROPOSED DAM ABOVE CRAIGIE'S BRIDGE.

Sketches of Power House and Machinery for Moving Lock Valves.

April, 1894.

Estimates by Engineers of Joint Board in 1894.

Estimate for Earth Dam and Lock. For Location 600 Feet above Craigie Bridge, exclusive of Drawbridge, Pavements and Fences. Dam 100 Feet Wide on Top and including Lock and Sluiceways. See Drawings for Details and Dimensions.

Summary.

Dam: —		
Earth filling,	$104,820 00	
Temporary shut-off,	22,000 00	
Discharge channel,	30,975 00	
Retaining wall,	123,514 00	
Total dam,		$281,309 00
Lock: —		
Coffer,	$31,742 00	
Excavation,	2,952 00	
Piles,	22,302 00	
4 lines sheet piling,	1,144 00	
Platform,	6,468 00	
Concrete,	23,798 00	
36-inch pipe,	1,000 00	
Tie rods,	900 00	
Wall masonry,	93,104 00	
Coping,	7,952 00	
Man-holes and gates,	1,008 00	
Cut range,	28,325 00	
Oak sheathing,	5,400 00	
Sliding valves, etc.,	21,000 00	
Roof on gate chamber,	4,000 00	
Pile guide piers,	7,000 00	
Power house and connections,	25,000 00	
Pumping inside coffer,	7,300 00	
Total lock,		290,395 00
		$571,704 00
Engineering superintendent and contingencies,		85,755 00
		$657,459 00
Call,		660,000 00

which is the figure given in the report of the Joint Board of 1894.

April 28, 1894.

The Same Estimate in Detail, giving the Unit Prices.

Earth Filling.

Below elevation — 7, 74,000 cubic yards at $0.35,		$25,900 00
Above elevation — 7 and between walls, 76,000 cubic yards at $0.60,		45,600 00
Above elevation — 7 outside, 14,000 cubic yards at $0.35,		4,900 00
Between lock and Charlesbank: —		
From top to elevation + 6, 31,000 cubic yards at $0.50,		15,500 00
From elevation + 6 to bottom, 34,000 cubic yards at $0.25,		8,500 00
There might be added to this for displacement of mud near harbor line: —		
On Boston side, 12,000 cubic yards at $0.25,	$3,000 00	
On Cambridge side, 4,000 cubic yards at $0.35,	1,420 00	
		4,420 00
		$104,820 00

Temporary Shut-off Dam.

¾ pile per lineal foot at $4.50,	$3 37	
Bracing: —		
58 ft. by 8 in. by 10 in. 184 ft. by 3 in. by 12 in. 116 ft. by 3 in. by 10 in. 50 ft. by 8 in. by 2 in. 136 ft. by 3 in. by 6 in. } 2,268 ft. B. M. ÷ 8 = 283 ft. at $0.03,	8 49	
8 in. by 12 in. by 23 ft. = 184 ft. B. M. at $0.02,	3 68	
Driving,	1 50	
Stop planks: —		
14 in. by 8 in. by 12 in. = 112 ft. B. M. at $0.02,	2 24	
Iron work,	2 00	
	$21 28	
For 900,		$19,152 00
For sand bags and extras,		2,848 00
Total for temporary shut-off dam,		$22,000 00

Details, Estimate of Joint Board of 1894 — **Continued.**

Discharge channels: —		
Timber inlet, 4 channels,		$2,432 00
Masonry channels — 10: —		
1,380 cubic yards brickwork at $15,	$20,700 00	
175 ft. coping,	175 00	
10 sets tide gates in place,	1,000 00	
10 shut-off valves,	750 00	
		22,625 00
Piling and timber foundation (10 channels): —		
700 piles at $4.50,	$3,150 00	
Platform: —		
2,430 ft. by 8 in. by 8 in., 81 by 120 ft. by 2 in., } 32,400 ft. B. M. at $24 per M.,	778 00	
		3,928 00
Crib at outfall: —		
12 M. ft. spruce at $20,	$240 00	
250 cubic yards stone at $3,	750 00	
Labor in placing,	1,000 00	
		1,990 00
		$30,975 00
Pile guide piers at end of lock,		$7,000 00

Retaining Walls.

	Per lineal foot.	
On upper side: —		
Coping, .23 cubic yard at $27,	$6 21	
Wall masonry, 2.08 cubic yards at $10.30,	21 42	
Ballast, .50 cubic yard at $1.40,	70	
Piles, $1\frac{3}{4}$, at $4.50,	7 88	
Platform, 44 ft. B. M. at $24 per M.,	1 05	
	$37 26	
15 per cent. (not including piles),	4 42	
Total,	$41 68	
Estimate for 1,108 ft.,		$46,181 00
Lower side: —		
Coping,	$6 21	
Wall masonry, 3.9 cubic yards at $10.30,	40 17	
Ballast, 1.5 cubic yard at $1.40,	2 10	
Piles, $2\frac{2}{3}$, at $4.50,	12 00	
Platform, 57 ft. B. M. at $24 per M.,	1 37	
	$61 85	
15 per cent. (not including piles),	7 47	
Total,	$69 32	
Estimate for 938 ft.,		65,022 00
On rock: —		
Coping,	$6 21	
Wall masonry, 3.9 cubic yards at $10.30,	40 17	
Split stone, 4 cubic yards at $15.17,	60 68	
	$107 06	
15 per cent.,	16 05	
Total,	$123 11	
Estimate for 100 ft.,		12,311 00
Total for masonry walls,		$123,514 00

Lock.

Coffer-dam per lineal foot: —		
$\frac{1}{4}$ pile at $4.50,	$1 12	
420 ft. B. M. hard pine sheathing at $24 per M.,	10 08	
For extra bracing,	2 00	
Driving sheet piling,	3 00	
24 ft. B. M. walings at $30 per M.,	72	
Tie rods and bolts, 13 lbs. at $0.05,	65	
Filling inside coffer, 13 cubic yards at $0.50,	6 50	
Filling outside coffer, $8\frac{1}{3}$ cubic yards at $0.25,	2 08	
Total,	$26 15	
Estimate for 1,080 ft.,		$28,242 00
For removing coffer and final dredging,		3,500 00
Total for lock and sluice coffer-dam,		$31,742 00

Details, Estimate of Joint Board of 1894—Continued.

Excavation inside of coffer:—
50 ft. by 70 ft. by 7 ft. = 24,500 cubic feet,
293 ft. by 310 ft. = 90,830 cubic feet,
45 ft. by 70 ft. by 7 ft. by 2 ft. = 44,100 cubic feet, } 5,905 cubic yards at 50 cents, $2,952 50

Wall masonry:—
107 ft. by 260 ft. = 27,620 cubic feet,
180 ft. by 200 ft. = 36,000 cubic feet,
358 ft. by 150 ft. = 57,750 cubic feet,
160 ft. by 7.5 ft. by 24 ft. = 28,800 cubic feet, } 5,564 cubic yards at $14, . . $77,896 00
51,360 cubic feet = 1,901 cubic yards at $8, ... 15,208 00
$93,104 00

Piles:—
4,956 at $4.50, ... $22,302 00

Platform:—
56 pieces 45 ft. by 10 in. by 10 in. = 21,000 ft. B. M.,
144 pieces 70 ft. by 10 in. by 10 in. = 84,000 ft. B. M.,
70 ft. by 4 in. by 360 ft. = 100,800 ft. B. M.,
45 ft. by 4 in. by 140 ft. = 25,200 ft. B. M., } 231,000 ft. B. M. at $28, . $6,468 00

Coping:—
124 ft.
350 ft.
100 ft. } 574 ft. narrow at $6.21, ... $3,564 54
170 ft. (8 ft. wide, $1\frac{1}{4}$ ft. thick, .37 cubic yard at $27) at $10 per ft., . 1,700 00
110 ft. (12 ft. wide, $1\frac{1}{4}$ ft. thick, .55 cubic yard at $27) at $15 per ft., . 1,650 00
$6,914 54
15 per cent., ... 1,037 17
$7,951 71

Tie rods and washers:—
90 rods at 250 pounds each = 22,500 pounds at $0.04, ... $900 00

Man-holes:—
9 man-holes and 7 gates at $112, ... $1,008 00

36-inch pipe and fittings:—
46 linear feet 36-inch pipe, say, ... $1,000 00

Oak sheathing of lock:—
90,000 feet B. M. at $60, ... $5,400 00

Cut range:—
45 ft. by $1\frac{2}{3}$ ft. by 360 ft. = 27,000 cubic feet,
22 ft. by $1\frac{2}{3}$ ft. by 100 ft. = 3,600 cubic feet, } 1,133 cubic yards at $25, . . $28,325 00

Concrete:—
Portland:—
3 ft. by 40 ft. by 310 ft.
14 ft. by 8 ft. by 310 ft. } = 71,920 cubic feet, 2,664 cubic yards at $7, $18,648 00

Rosendale:—
14 ft. by 11 ft. by 160 ft. = 24,640 cubic feet,
125 ft. by 2 ft. by 5 ft. = 1,250 cubic feet,
120 ft. by 4 ft. by 4 ft. = 1,929 cubic feet, } 1,030 cubic yards at $5, 5,150 00
$23,798 00

Sliding valves:—
Weight of iron in gate, 110,400 pounds at $0.05, . $5,520 00
44 rollers and chairs, at $25, ... 1,100 00
4 gates and sluiceways, ... 1,170 00
$7,790 00

Allow for things not designed, ... $2,000 00

For 2 gates, say $10,000 each, ... $20,000 00
Special sealing adjustment at entrance to gate chamber, ... 1,000 00
Roof over gate chamber, ... 4,000 00

Pumping inside coffer-dam:—
Say 2 8-inch centrifugal pumps at $10 each per day for one year, ... $7,300 00

Four lines sheet piling for cut-off across lock:—
35,200 ft. B. M. 4-inch tongued spruce at $20 per M., ... $704 00
Driving 440 linear feet sheeting at $1, ... 440 00
$1,144 00

Details, Estimate of Joint Board of 1894—Concluded.

Power House and Connections.

House,	$8,000 00	
2 boilers,	2,500 00	
1 30-horse-power engine,	1,500 00	
1 air compressor,	1,200 00	
2 drainage pumps,	2,000 00	
1 force pump,	800 00	
300 feet shaft conduit,	2,000 00	
400 feet 4-inch shafting and fitting,	1,000 00	
3,500 pounds gears at $0.08,	280 00	
200 feet link chain, 9,700 pounds at $0.10,	970 00	
		$20,250 00
Say,		$25,000 00

Estimates of Cost by Percy M. Blake, C.E., 1902.

As a further confirmation of the estimates of cost of the dam and lock, we had the figures of Mr. Blake, given on page 191 of the evidence of 1902. These were based on the Craigie bridge site, and on prices of to-day, for a dam 120 feet wide on top, and included a lock 40 feet in width and 356 feet long between gates, with sill 12 feet below mean low water, and included 8 storm water sluices of a total effective area of 520 square feet, and also included an overfall spillway 100 feet long, with crest at elevation 5. The height of this dam was to be elevation 17.0 above Boston base, or the same height proposed by the Joint Board in 1894.

It will be noted that the dam proposed by Mr. Blake was 20 feet wider than that of the Joint Board, and had a lock 37 feet longer and 2 feet deeper, and had storm sluices of about 200 square feet greater area (about 60 per cent. larger), and in addition to this a spillway with a 100-foot overfall, not before provided for.

For this structure (exclusive of certain other sluices called the tidal sluices, which are no longer proposed and were not favored by Mr. Blake) he estimated the total cost (p. 238 of evidence) at $1,075,000. This, except for its larger lock, larger sluices and the spillway added, is strictly comparable with the Joint Board estimate as revised to $870,000.

Mr. Blake has kindly furnished me with the details for this estimate, as follows. They are of value as an independent judgment upon the unit prices appropriate to this location. It will be noted that the items of costs are grouped mainly according to the kind of material rather than according to a sub-division into structural units, as dam, lock, sluices, etc. There were some slight modifications in plan and readjustment of quantities in his final revision, whereby the totals here given do not foot up exactly as above, but the following figures serve to show his unit prices, and give a close approximation to the quantities of material.

To compare this structure proposed by Mr. Blake with the high dam finally recommended by the committee of 1902, the principal addition to be made to the Blake figures is that due to raising the grade so that tow boats and mastless barges can pass under without opening the draw.

If this is done by a steel trestle, as proposed in J. R. F., study C, the extra cost will be, for 130 feet width of deck, about $150 per linear foot, or 150 by 1,270, for steel and concrete,	$190,500
For pile and concrete foundations to trestles, 1,050 piles and 1,975 cubic yards concrete, about,	19,000
For construction of inclined approaches back of shore lines, per estimate of William Jackson, city engineer (Appendix No. 13, p. 2, design No. 3),	114,000
A more elaborate drawbridge than figured by Mr. Blake will add, say,	30,000
Total to be added for extra height, etc.,	$353,500
Original Blake estimate (without tidal sluices),	1,075,000
Blake estimate plus allowance for raising grade.	$1,428,500

By a rough off-hand comparison it appears that the extra masonry in Mr. Blake's design for spillway and sluices will more than offset the extra masonry required in the deeper lock and outlets of marginal sewers in Mr. Freeman's design; and it will further be noted, on inspecting Mr. Blake's outline drawing at page 191 of volume of evidence, that his design and estimate included several ornamental towers, that called for $19,500 of this cost. So that in a general way we may say that the Blake estimate, modified to meet the increased height and increased dimensions recommended by the committee of 1902, would be about $1,400,000.

Details of Blake Estimate, 1902.

Preliminary Approximate Estimate of Cost by Percy M. Blake, February, 1902.

Dam at Craigie bridge, 120 feet wide, 1,270 feet long. (Sums as found in book of original computations not rearranged and classified for publication.)
(The quantities first given below include tidal sluices, afterward deducted.)

Stone masonry: —	
Walls and piers, 39,153 cubic yards at $12,	$469,836
Arches and tidal sluices, 333 cubic yards at $24,	7,992
Retaining walls, 5,203 cubic yards at $9,	46,827
Coping, 2,460 lineal feet at $2,	4,920
Parapets, 959 cubic yards at $14,	13,426
Concrete, 16,813 cubic yards at $8,	134,504
Towers, roofs: —	
Four small ones at $1,500,	6,000
One large one,	3,500
One small one,	2,000
Windows and ornamental work,	8,000
Earth embankment, 277,352 cubic yards at $0.90,	249,616
Piling for retaining walls, 1,378 lineal feet at $12,	16,536
Packing and reinforcing around walls, 1,378 lineal feet at $3,	4,134
Paving, 2 feet thick between piers, 619 square yards at $6,	3,714
Iron fence, etc., 2,540 lineal feet at $3,	7,620
Sidewalks, 2,822 square yards at $2.50,	7,055
Roadway surfacing (less sluices, etc.), 8,024 square yards at $1.00,	8,024
Flooring, wasteway sluices, 11,684 square feet at $1.50,	17,526
Flooring, tidal sluices, 19,596 square feet at $1.50,	29,394
Flooring, regulating ports, 8,464 square feet at $1.50,	12,696
Drawbridge over lock (3 sections),	20,000
Drawbridge flooring, 4,800 square feet at $1.50,	7,200
Piles (including caps, braces, etc.) for lock fenders, 244 at $30,	7,320
Gate chambers, lining and flooring, 2, at $8,000,	16,000
Channels for filling lock, 534 lineal feet at $30,	16,020
Cribs for submerged inlet,	8,000
Wasteway sluices, 5, at $3,000,	15,000
Tidal sluices, 5, at $8,000,	40,000
Regulating ports, gates, 8, at $1,200,	9,600
Check valves on regulating ports, 4, at $3,000,	12,000
Rolling gates in lock, 2, at $7,500,	15,000
Shafts and gearing for wasteway sluices,	3,500
Shafts and gearing for tidal sluices,	12,000
Shafts and gearing for regulating ports,	6,000
Motors for wasteway sluices,	2,500
Motors for tidal sluices,	3,500
Motors for regulating ports,	2,500
Interior finish, hoists and floors for motor house,	4,000
Interior finish, hoists and floors for shaft house, 4 houses at $1,500,	6,000
Filling power house grounds to elevation 17 (lock to Cambridge shore), 18,880 cubic yards at $0.60,	11,328
Power house,	15,000
Steam plant, machinery and generators,	18,000
Electric wires and switch boards for all motors,	5,000
Total, including tidal sluices,	$1,308,788

If tidal sluices are not used, deduct as follows: —

Stone masonry: —

Walls and piers, 11,695 cubic yards at $12,		$140,340
Arches, 333 cubic yards at $24,		7,992
Parapet, 493 cubic yards at $14,		6,902
Concrete, 2,653 cubic yards at $8,		21,224
Roofs, motor house,		3,500
Roofs, small house adjoining,		2,000
Roofs, shaft house,		1,500
Window and ornamental work,		5,000
Flooring, 19,596 square feet at $1.50,		29,394
Tidal sluices, 5, at $8,000,		40,000
Shafts and gearing for sluices,		12,000
Motors for sluices,		3,500
Interior finish, hoists and floors for motor house,		4,000
Interior finish, hoists and floors for shaft house,		1,500
Paving between piers, 240 square yards at $6,		1,440
Deduct,		$280,292

Add for items in substitution for tidal sluices if these are not adopted: —

Stone masonry, 184 cubic yards at $12,	$2,208	
Concrete, 48 cubic yards at $6,	288	
Roof,	1,500	
Windows and ornamental work,	1,000	
		$4,996
Paving slopes on embankment, 4,348 square yards at $2,	$8,696	
Road surfacing, 2,177 square yards at $1,	2,177	
Retaining walls, 1,503 cubic yards at $9,	13,527	
Earth embankment, 30,009 cubic yards at $0.90,	27,008	
		51,408
		$56,404

Net saving if tidal sluices are not adopted, $280,292 — $56,404 = $223,888.

(This corresponds to Mr. Blake's statement, p. 237 of evidence, that by omitting the tidal sluices about $225,000 would be saved.)

Net cost of dam, lock, storm sluices, spillway and drawbridge, $1,308,788 — $223,888 = $1,084,900.

By some minor readjustments the sum of $1,075,000 was finally reached.

First Estimates by J. R. Freeman, C.E.

For my estimates presented on Jan. 13, 1902, I took the estimate of the Joint Board of 1894 ($660,000) as a basis, first adding to it 10 per cent. for general increase of prices, thus making it $726,000, and then estimated the additional quantities of earth filling and masonry required for the increased width and increased height of the bridge, and also the increase required by reason of the channel area being deeper at the Craigie bridge site now proposed than it is at the location 600 feet farther up stream suggested by the Joint Board of 1894; and after adding the estimated cost of the drawbridge and allowing for a lock 5 feet wider and 3 feet deeper and 37 feet longer than that provided for by the Joint Board, and adding to this an allowance of $115,000 for the approaches on slopes outside of the limits of the bridge proper (the same figure adopted by Mr. Jackson for his third design, p. 430 of Appendix 13), I reached a total about $590,000 larger than that of the Joint Board, thus nearly doubling their estimate; and I then concluded that the high dam 130 feet wide, with lock sills 13 feet below mean low water, dam, lock, draw and sluices, all complete, could be built for $1,250,000; and for an approximate check used the unit prices and quantities of the Blake estimate above given.

Having, as previously explained, considered that the sanitary questions and questions about the possible shoaling of the harbor were paramount, I had devoted most of the time to them, and had not proposed presenting detailed estimates of cost based on designs of my own.

Revised Estimates by J. R. Freeman.

Four weeks later (Feb. 11, 1903), at the hearing before the committee on metropolitan affairs of the Massachusetts Legislature, the question of a deeper lock was presented with renewed force by the representatives of certain of the navigation interests, and I opposed this greater depth earnestly at that time, on the grounds of expense and sacrifice of sluiceway involved in making these lock gates so large that they could not be opened or shut under pressure, having previously given it some study.

Immediately afterward I gave this question of depth of lock further study, with a view to providing additional sluiceways in the most economical manner possible in order to compensate for the sacrifice in ability to use the lock as a sluiceway, because of the increased size of the lock gates, and finally concluded that the deep lock was feasible and desirable.

I was asked, on behalf of the mayor, by the city engineer of Boston, to submit copies of my estimates in detail. Subsequently, at a conference with Mayor Collins, I was requested to also submit estimates on a design from which all elaboration not strictly necessary had been cut out. Further sketches and estimates have therefore been made, and I have elaborated my rough preliminary sketches into the drawings which follow. The deep-lock design has been adopted as the basis of all of these estimates.

In adopting the deeper lock, which in turn necessitated much larger sluiceways than those shown on the plan of the Joint Board of 1894, and in providing for the marginal conduits not contemplated by the Joint Board, and in order to meet the new requirement contemplated in keeping ice broken in the main channels, I was led to make somewhat radical changes in the arrangement of these sluiceways, and to incorporate with them devices for running out ice, somewhat similar to those which have been built from my designs for certain water power canals. I have also adopted larger areas for the gates designed to let out the flood waters of great rain storms or from melting of snow in the Charles River water-shed, or to be used in drawing down or flushing the basin; but these gates are surely feasible, for they are no larger and indeed not so large as many that have long been in successful use under much more severe duty on certain water power canals.

In connection with these flood sluices the various details were worked out for the outlet of the marginal conduits, which it is now proposed shall bring down the storm overflows of the sewerage system and the polluted flow of Stony Brook, together with the water used for circulation and the flushing out of the Fens basin and the Broad and Lechmere canals.

After making these later studies, and finding that any reasonable amount of sluiceway desired can be cheaply provided outside the lock, and particularly after reviewing the inconveniently cramped space between the Craigie bridge and railroad bridge, in which vessels must wait if lock is not of full depth, I have become convinced that the deep lock, with down-stream sill 18 feet below mean low water, is feasible and is probably worth its extra cost; for with this depth of lock any vessel drawing 16 or 17 feet, or even a little more, can at almost any ordinary stage of tide, even at mean low water, proceed directly into the basin without having to tie up in the narrow space between the Lowell freight bridge and the dam. *This depth or size for lock cannot be wholly justified by amount and size of the present shipping on the Charles, but by the hope for larger boats and more boats in future.*

I have elsewhere in this report stated the opinion that the dam should foster a larger commerce in the future and aid in developing a great manufacturing district in Cambridgeport, and I also venture to suggest that, *if the dam and deep lock bring this great gain over present conditions, the navigation interest may very properly make concessions in their demands for dredging and repairing walls within the canals.*

I would most earnestly favor the high bridge rather than one at the present grade of Craigie bridge, because of the growing importance of this main thoroughfare to foot travel, teams and street cars, and the desirability of reducing the drawbridge openings to a minimum.

Twenty years hence this will be more important even than now, and this raising of the clear space under the bridge in order to avoid interruption to travel will be in line with what has been done at Cambridge bridge and Charlestown bridge.

It thus happens that three very different designs for the dam are presented, either of which may or may not be provided with catch-basins for catching the sludge from street wash and pollution in the marginal conduits,* thus making six different plans in all, *ranging in cost all the*

---

* These catch-basins were designed to lessen the deposit of sludge in the harbor immediately below the dam, and to facilitate its collection by methods somewhat similar to those followed at the deposit sewer at the pumping station at Old Harbor Point; removal to be done by pumping the soft material into scows screened from view in the slips beneath the bridge, perhaps by pumping arrangements similar to those employed with the well-known odorless excavators, or, if the street wash gave too hard a sediment for this, by a dredge bucket suspended from a movable crane or trolley, like coal unloaders.

A good deal of foul sludge is at present deposited near the Bridge Street sewer outlet, and 5,000 cubic yards of this has been removed during the past summer by the city of Cambridge by ordinary methods of dredging.

Sludge deposits now occur at the Binney Street sewer outlet and in the Fens, or wherever the salt water acts as a precipitant to the pollution in fresh water.

The city engineer of Cambridge at my request has compiled some statistics of the dredging in the Charles basin near the sewer outlets, as follows: —

From near Bridge Street sewer outlet: —

	Cubic Yards.		Cubic Yards.
1883,	4,516	1893,	3,362
1884,	6,704	1894,	3,841
1885,	5,300	1895,	–
1886,	6,150	1896,	2,727
1887,	4,820	1897,	5,150
1888,	4,520	1898,	–
1889,	3,476	1899,	–
1890,	3,322	1900,	–
1891,	3,590	1901,	–
1892,	3,523	1902,	4,938

The north metropolitan sewer was completed and in use in 1895.

Prior to about 1898 the sewage from the Somerville slaughter houses was not received into the new metropolitan sewer.

From near Binney Street sewer outlet: —

1896, 7,020 cubic yards. No other dredging recorded at Binney Street outlet.

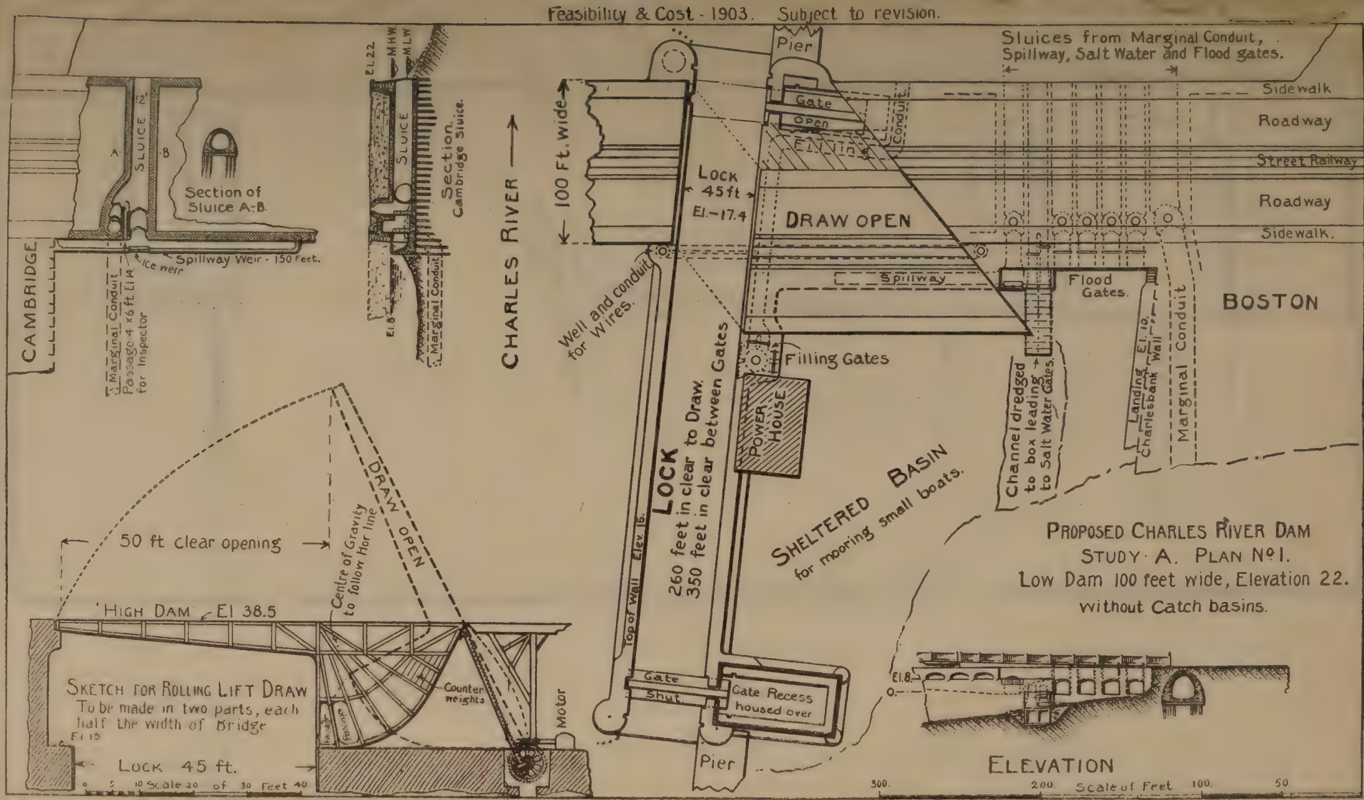
From the absence of any record of dredging near the smaller sewer overflows, and from examining the river bed near them, it appears that the natural forces of dilution, bacterial action and decomposition are sufficient to take care of the discharge from the smaller districts without the production of offensive conditions, but that the limit is passed in the case of the Binney Street and Bridge Street sewer overflows and Stony Brook.

Therefore, for some years to come, until the separate system of sewers makes great progress, and perhaps afterward if the putrescible dirt in street wash should ever increase, largely because of more horses or less efficient sweeping, there will doubtless be a considerable deposit of sludge where the outfall of these marginal conduits mingles with the salt water.

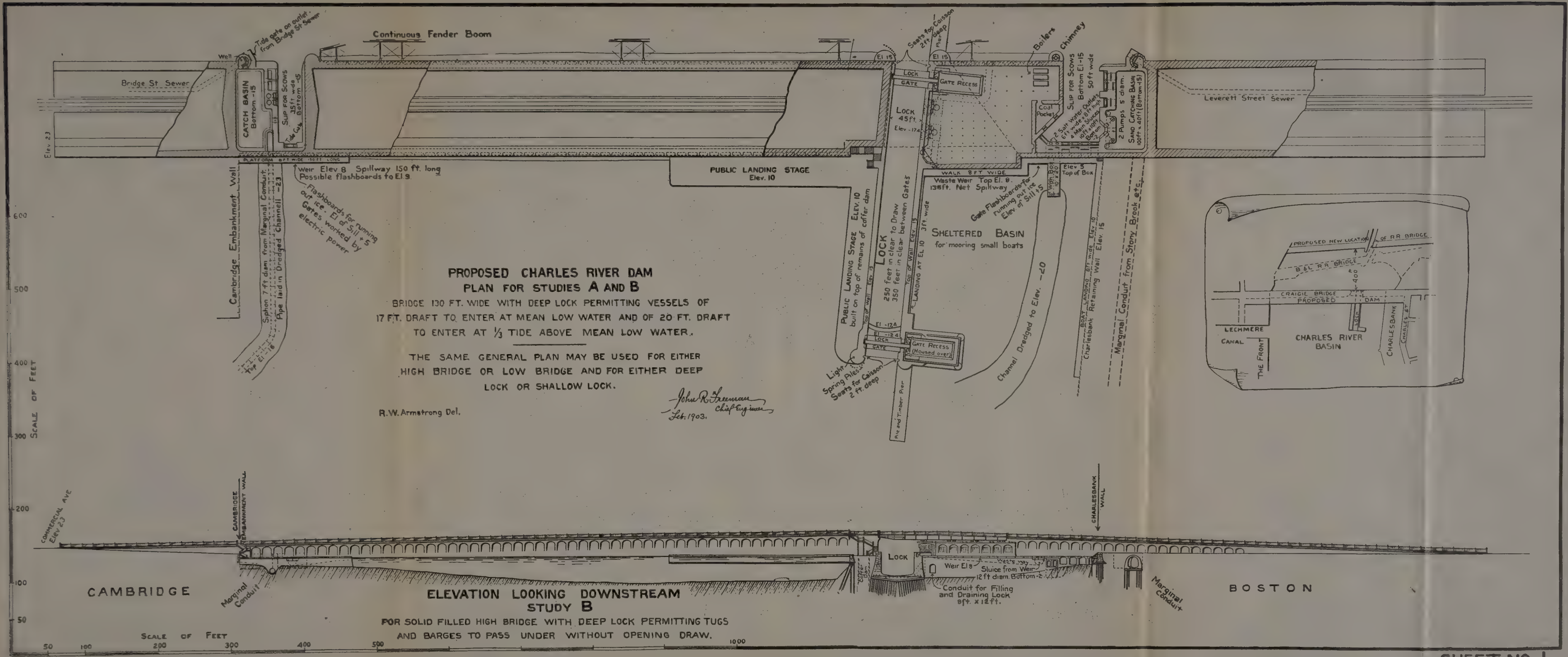
This, if left to itself, will be deposited mainly in the basin just below the dam, and in the open parts of the basin can be easily dredged, just as it is now dredged near the Bridge Street sewer.

If catch-basins are adopted, the details will require some further study (perhaps it would be best to make the scow slips smaller and the catch-basins larger); but it is believed the estimate of cost here made for them will cover any real necessity.

Catch-basins add $101,000 to the cost of the first design; catch-basins add $114,000 to the cost of the second design; catch-basins add $123,000 to the cost of the third design.

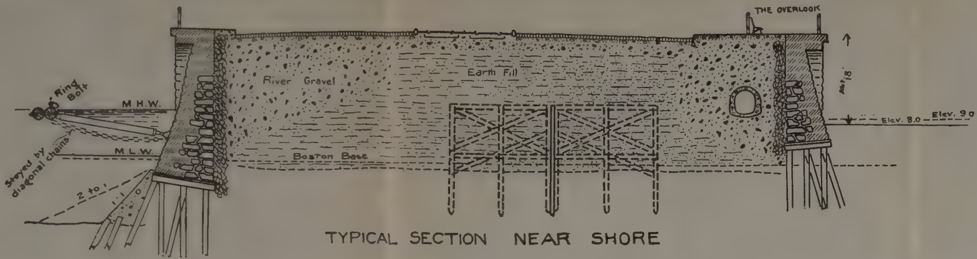

Feasibility & Cost - 1903. Subject to revision.
Sluices from Marginal Conduit, Spillway, Salt Water and Flood gates.
Sidewalk
Roadway
Street Railway
Roadway
Sidewalk.
BOSTON
Marginal Conduit
Landing El. 10. Charlesbank Wall
Flood Gates.
Channel dredged to box leading to Salt Water Gates.
Spillway
DRAW OPEN
Gate Open
Conduit
Pier
Lock 45 ft
El. -17.4
100 Ft. wide
Filling Gates
Power House
LOCK
260 feet in clear to Draw.
350 feet in clear between Gates
Top of Wall Elev. 16.
Well and conduit for Wires.
Gate Shut
Gate Recess housed over
Pier
SHELTERED BASIN for mooring small boats.
PROPOSED CHARLES RIVER DAM
STUDY · A. PLAN No. 1.
Low Dam 100 feet wide, Elevation 22.
without Catch basins.
El. 8
ELEVATION
300. 200. Scale of Feet 100. 50.
CHARLES RIVER
CAMBRIDGE
SLUICE
A
B
12'
Section of Sluice A-B.
Spillway Weir - 150 Feet.
Ice weir
Marginal Conduit
Passage 4 x 6 ft El 14 for Inspector
El. 22
MHW
MLW
SLUICE
Section. Cambridge Sluice.
El. 8
Marginal Conduit
50 ft clear opening
DRAW OPEN
Centre of Gravity to follow Hor line
'HIGH DAM' El 38.5
Counter weights
Motor
SKETCH FOR ROLLING LIFT DRAW
To be made in two parts, each half the width of Bridge
El 15
LOCK 45 ft.
0 5 10 Scale 20 of 30 Feet 40

PRELIMINARY STUDIES — FEASIBILITY AND COST 1903 — SUBJECT TO REVISION.

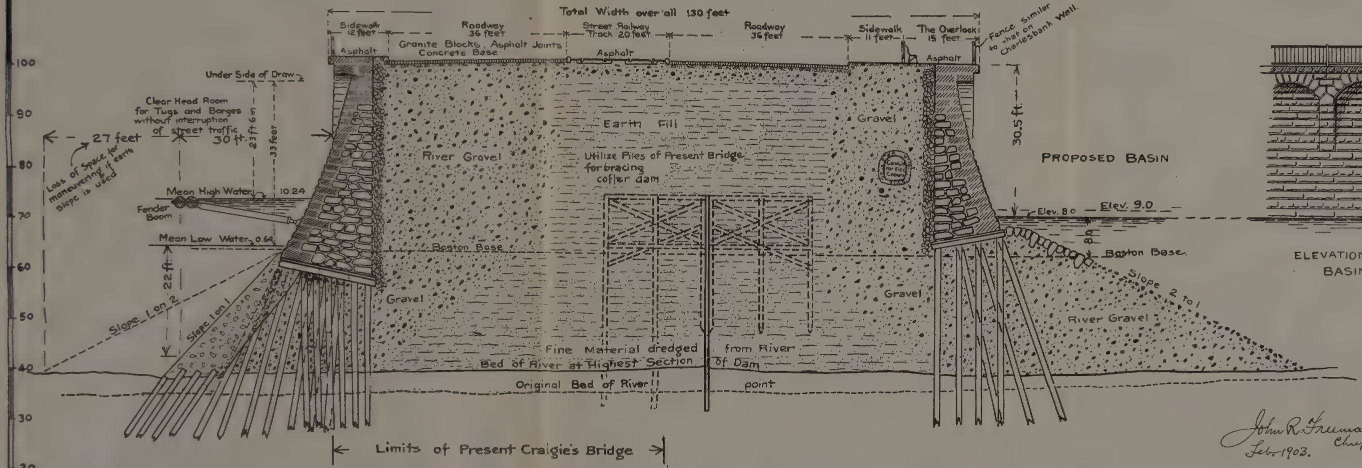


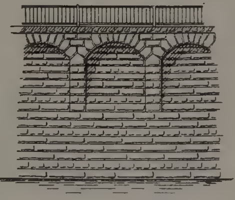
SHEET NO. 1

PRELIMINARY STUDIES — FEASIBILITY AND COST 1903 — SUBJECT TO REVISION.



TYPICAL SECTION NEAR SHORE





ELEVATION OF DAM BASIN SIDE

John R. Freeman
Chief Engineer
Febr 1903.

TYPICAL SECTION AT MAXIMUM HEIGHT

PROPOSED CHARLES RIVER DAM

STUDY B – FOR HIGH DAM WITH SOLID FILLING

PERMITTING PASSAGE OF TUGS AND BARGES WITHOUT OPENING THE DRAW BRIDGE

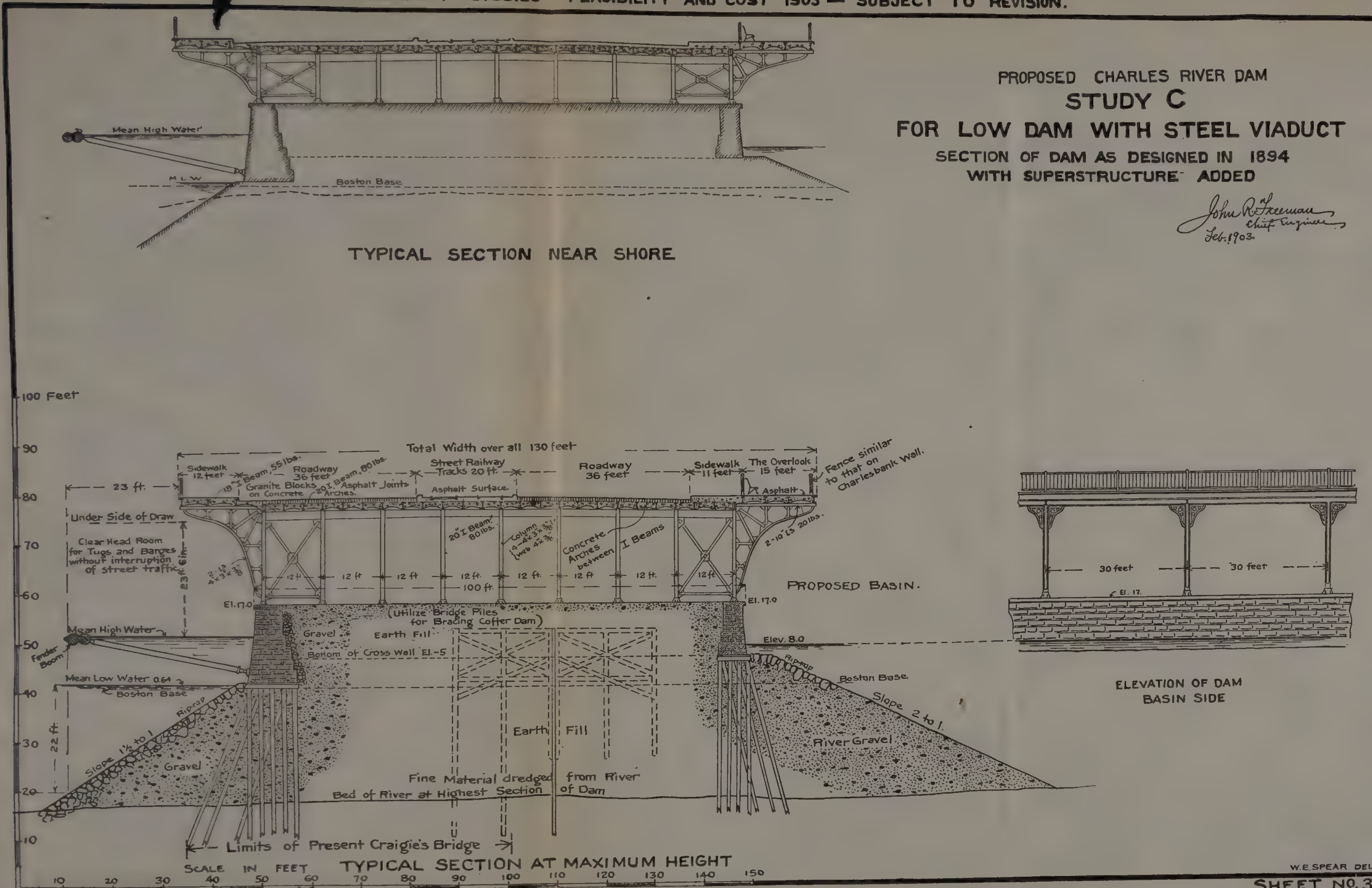
SCALE IN FEET

10 20 30 40 50 60 70 80 90 100 110 120 130 140 150

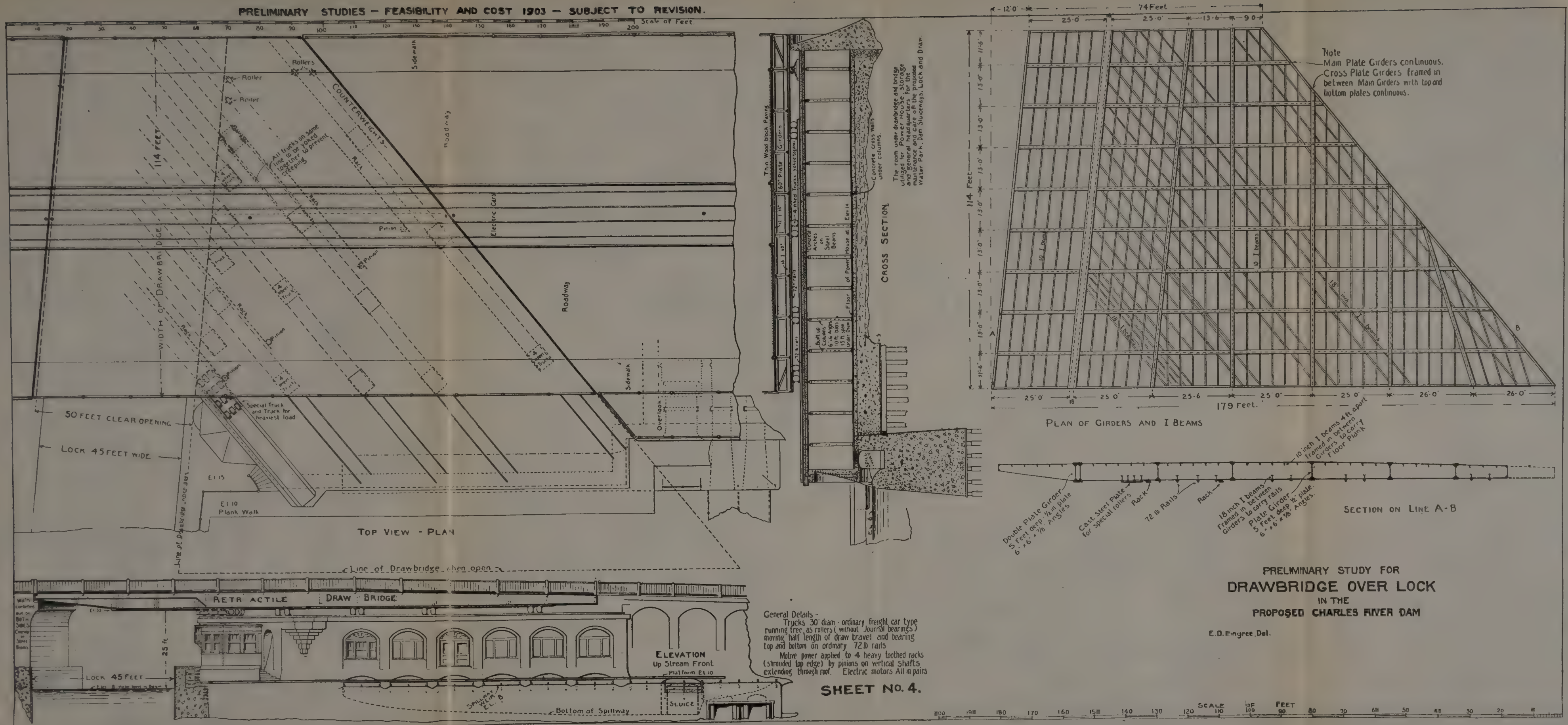
W E SPEAR DEL

SHEET No. 2

PRELIMINARY STUDIES — FEASIBILITY AND COST 1903 — SUBJECT TO REVISION.

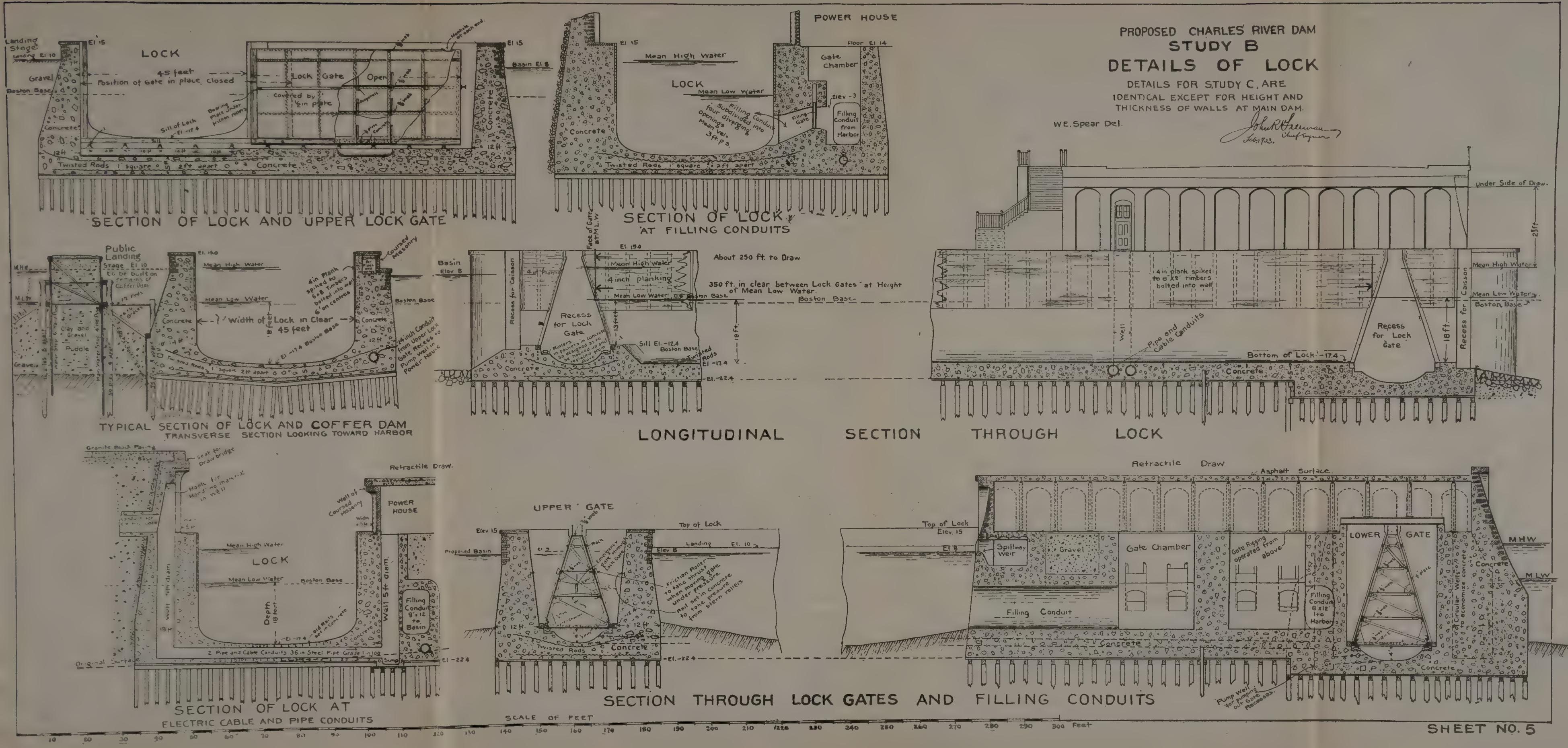


SHEET NO. 3

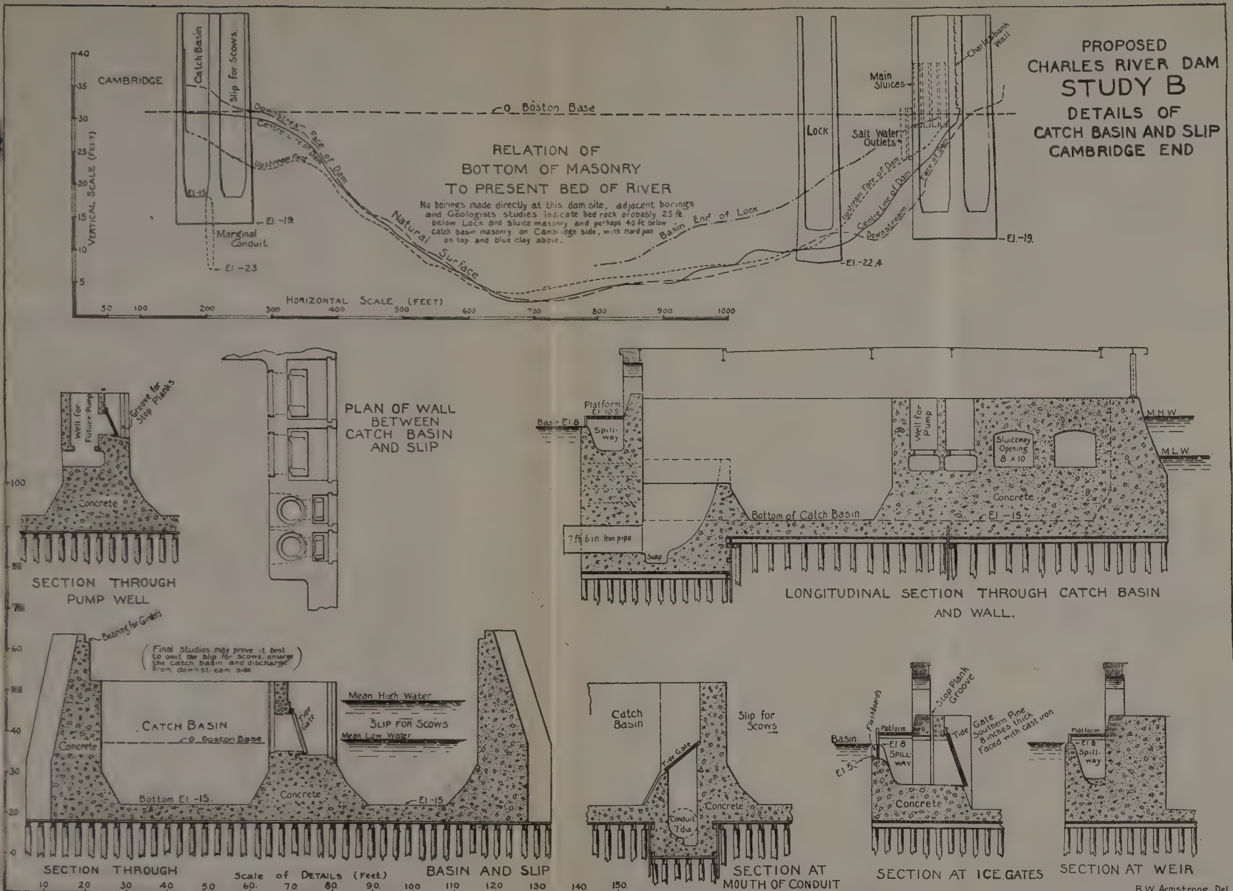


PRELIMINARY STUDIES — FEASIBILITY AND COST 1903 — SUBJECT TO REVISION.
Scale of Feet
Rollers
Roller
Roller
COUNTERWEIGHTS
Sidewalk
Roadway
114 FEET
All trucks on same line to be yoked together to prevent creeping
Rack
Pinion
Electric Cars
WIDTH OF DRAWBRIDGE
Roadway
Special Truck and Track for heaviest load
50 FEET CLEAR OPENING
LOCK 45 FEET WIDE
Sidewalk
Overlook
El 15
El 10
Plank Walk
TOP VIEW - PLAN
Line of Drawbridge when open
Thin Wood block Paving
60" Plate Girders
4 wheel Trucks yoked together
Concrete Arches on Steel Beams
Floor of Power House at El 14
Built up Columns
Concrete cross walls under columns.
The room under drawbridge and bridge utilized for Power House, storage and general headquarters for the maintenance and care of the proposed Water Park, Dam Sluiceways, Lock and Draw
CROSS SECTION
74 Feet
12.0
25.0
25.0
13.6
9.0
114 Feet
Note
Main Plate Girders continuous.
Cross Plate Girders framed in between Main Girders with top and bottom plates continuous.
10 I beams
18 inch I beams
25.0
25.0
25.6
25.0
25.0
26.0
26.0
179 feet.
A
B
PLAN OF GIRDERS AND I BEAMS
10 inch I beams 4 ft. apart framed in between Girders to carry Floor Plank
Double Plate Girder 5 feet deep ½ in plate 6"×6"×7/8 Angles
Cast Steel Plate for Special rollers
Rack
72 lb Rails
Rack
18 inch I beams framed in between Girders to carry rails
Plate Girder 5 Feet deep ½ plate 6"×6"×7/8 Angles.
SECTION ON LINE A-B
RETRACTILE DRAW BRIDGE
25 ft
LOCK 45 FEET
ELEVATION
Up Stream Front
Platform El 10
Spillway Weir El. 8
Bottom of Spillway
SLUICE
General Details -
Trucks 30" diam - ordinary freight car type running free, as rollers (without Journal bearings) moving half length of draw travel and bearing top and bottom on ordinary 72 lb rails
Motive power applied to 4 heavy toothed racks (shrouded top edge) by pinions on vertical shafts extending through roof. Electric motors All in pairs
SHEET No. 4.
SCALE OF FEET
PRELIMINARY STUDY FOR
DRAWBRIDGE OVER LOCK
IN THE
PROPOSED CHARLES RIVER DAM
E.D. Pingree, Del.

PRELIMINARY STUDIES — FEASIBILITY AND COST, 1903 — SUBJECT TO REVISION.



PRELIMINARY STUDIES — FEASIBILITY AND COST 1903 — SUBJECT TO REVISION



SHEET. No.6.

way from about a million dollars to somewhat more than one and a half million dollars, the first-named being for a thoroughly excellent and practicable structure, while the sixth is for a structure believed to be the most expensive and elaborate that any reasonable ground can be found for under the existing conditions.

Unit Prices used in the Following Estimates of the Cost of the Proposed Charles River Dam.

Excavation (largely used for filling esplanade, etc.): —	
Removal of soft material from bed of river,	$0 30 per cubic yard.
Trenching and excavation in banks,	50 " " "
Fill (mostly taken from bed of river): —	
Puddle within coffer-dams and main dam,	$0 50 per cubic yard.
Material dumped around outside of coffer-dams,	30 " " "
Earth embankment,	40 " " "
Gravel under wall platforms,	50 " " "
Gravel back of walls,	60 " " "
Gravel under lock, rammed in thin layers,	80 " " "
Broken stone backing for walls,	1 50 " " "
Lumber (plus labor on same to put in place): —	
Round piles under platforms (driven),	$0 12 per linear foot.
Round piles in piers (driven),	20 " " "
Round fender piles (driven),	30 " " "
Square timber (in place),	$40 to $45 per M.
Built-up sheet piling (in place),	40 per M.
Plank in platforms, etc.,	$35 to 50 per M.
Chestnut for lining lock,	60 per M.
Oak caps,	80 per M.
Masonry: —	
Granite walls, cut like those of Charlesbank,	$12 00 per cubic yard.
Granite arches,	30 00 " " "
Cement concrete walls,	7 00 " " "
Cement concrete in arched floors, etc.,	10 00 " " "
Slope paving,	6 00 " " "
Riprap on bottom,	2 00 " " "
Structural steel and iron: —	
Steel I beams and angles in place,	$60 00 per ton.
Plate work in lock gates and caisson,	100 00 " "
Ornamental railing for bridge (like Charlesbank),	160 00 " "
Paving: —	
Granite block paving with concrete bed,	$4 00 per square yard.
Granite block paving on concrete bed,	2 50 " " "
Asphalt surfacing for sidewalks and landings,	2 50 " " "

The Location favors Low Costs.

In connection with the unit prices it must be noted that the location of the dam and lock is one that favors low costs. The geologist reports favorably on the substrata. There is doubtless ledge near low-tide level at the Boston end, but the river bed here generally is composed of a shallow deposit of mud, with hard blue clay beneath and boulder clay beneath this. Borings planned here were interrupted by severely cold weather. Piles and all kinds of stone can be brought cheaply by water or rail close to the site proposed. There are excellent gravel deposits in the bed of the Charles a few hundred feet up stream, easily dredged, and for which the regular price in the bank is said to be 12 cents per cubic yard (see also evidence, pp. 84–86), and excellent gravel is also said to be obtainable, suitable for cheap concrete or suitable for the back-filling of high walls, by scows from points down the harbor where bars are being removed by dredging.

Puddle and other filling can be cheaply had by dredging, and at the same time improve the channels of the basin. The main freight yard of the northern and western railroads is close at hand; a spur track

could be run onto the dam site, if desired, for bringing broken stone directly to the concrete mixer; and the site is convenient to the homes of a large working population of mechanics and laborers. At the Cambridge bridge site, only half a mile away, many piles are reported to have been driven with great rapidity and low cost during the past two seasons, and the conditions for cheap pile-driving by powerful apparatus were found very favorable.

PROPOSED CHARLES RIVER DAM

Preliminary Estimate of Cost — J. R. Freeman Chief Engineer.

PLAN No. 1. LOW DAM, 100 FEET WIDE, TOP AT ELEVATION 22, **WITHOUT CATCH BASINS.**

Containing Deep Lock Retractile Draw, Ice Weirs and Flood Sluices.

Computations by W. E. Spear and E. D. Pingree, Ass't Eng'rs

Portion of Structure.	Excavation	Earth Fill		Lumber		Masonry		Structural Steel & Iron.	Pavements and Walks.	Power Plant Gates & Machinery	Total.
		Gravel	Puddle	Piles (Driven)	Lumber (in place)	Concrete (Cement)	Granite like Charlesbank				
Coffer Dams.											
Lock and Boston End.	—	6,720.	18,075.	3,390.	34,424.	—	—	2,785.	—	—	65,394.
Cambridge End.	—	—	5,800.	960.	10,480.	—	—	250.	—	—	17,490.
Middle, or Main Shut-off Dam.	—	—	—	4,800.	20,960.	—	—	1,000.	—	—	26,760.
Pumping out Coffers.	—	—	—	—	—	—	—	—	—	—	.9.000.
Removal of Coffers.	—	—	—	—	—	—	—	—	—	—	7,000.
Construction.											
Lock Complete. Drawbridge and its Immediate Supports. Power House.	4,915	9,540.	—	26,400.	20,210.	200,900.	14 396	58,385	—	48,300.	383,046.
Flood Sluices Two Spillways and Ice Run-offs. Two Sewer Outlets.	4,125.	1,400.	2,395.	8,450.	6,750.	58,940.	8,280.	1,690.	—	13,400.	105,430.
Main Dam.	7,800	45,225.	41,840.	16,755.	5,665.	1,500.	109,830.	1,000.	—	—	229,615.
Approaches to meet New Grade.	—	—	—	—	—	—	—	—	—	—	—
Pavements and Walks.	—	—	—	—	—	—	—	—	44,920.	—	44,920.
Railings.	—	—	—	—	—	—	—	5,712.	—	—	5,712.
Totals.	16,840.	62,885.	68,110.	60,755	98,489	261,340.	132,506.	70,822	44,920.	61,700.	$ 894,367.
Engineering and Contingencies.											89,433.
Whole Structure.											$ **983,800.**

PROPOSED CHARLES RIVER DAM

Preliminary Estimate of Cost — J. R. Freeman, Chief Engineer.

PLAN No. 2. LOW DAM, 100 FEET WIDE, TOP AT ELEVATION 22, WITH CATCH BASINS.

Containing Deep Lock, Retractile Draw, Ice Weirs and Flood Sluices.

Computations by W. E. Spear and E. D. Pingree, Ass't Eng'rs.

Portion of Structure	Excavation	Earth Fill		Lumber		Masonry		Structural Steel & Iron.	Pavements and Walks.	Power Plant Gates & Machinery	Total.
		Gravel	Puddle	Piles (Driven)	Lumber (in place)	Concrete (Cement)	Granite like Charlesbank				
Coffer Dams.											
Lock and Boston End.	—	6,720.	18,075.	3,390.	34,424.	—	—	2,785.	—	—	65,394.
Cambridge End.	—	—	5,800.	960.	10,480.	—	—	250.	—	—	17,490.
Middle, or Main Shut-off. Dam.	—	—	—	4,800.	20,960.	—	—	1,000.	—	—	26,760.
Pumping out Coffers.	—	—	—	—	—	—	—	—	—	—	9.000.
Removal of Coffers.	—	—	—	—	—	—	—	—	—	—	7,000.
Construction.											
Lock Complete. Drawbridge and its Immediate Supports. Power House.	4,915	9,540.	—	26,400	20,210,	200,900.	14,396.	58,385.	—	48,300.	383,046.
Flood Sluices Two Spillways and Ice Run-offs. Two Catch Basins	13,080.	2,070.	—	7.920.	8,660.	132,900.	5,688.	22,860.	—	18,900.	212,078.
Main Dam.	7,275.	42,195.	38,790.	16,100.	5,445.	1,500.	102,260.	1,000.	—	—	214,565.
Approaches to meet New Grade.	—	—	—	—	—	—	—	—	—	—	—
Pavements and Walks.	—	—	—	—	—	—	—	—	44,920.	—	44,920.
Railings.	—	—	—	—	—	—	—	5,712.	—	—	5,712.
Totals.	25,270.	60,525.	62,665.	59,570.	100,179	335,300	122,344.	91,992	44,920.	67,200.	$ 985,965
Engineering and Contingencies.											98,600.
Whole Structure.											$1,084,600.

PROPOSED CHARLES RIVER DAM

Preliminary Estimate of Cost — J. R. Freeman, Chief Engineer.

PLAN No. 3. LOW DAM, 100 FEET WIDE, WITH STEEL VIADUCT, WITHOUT CATCH BASINS.

Containing Deep Lock, Retractile Draw, Ice Weirs and Flood Sluices.

Computations by W. E. Spear and E. D. Pingree, Ass't. Eng'rs.

Portion of Structure.	Excavation	Earth Fill		Lumber		Masonry		Structural Steel & Iron.	Pavements and Walks.	Power Plant Gates & Machinery	Total.
		Gravel	Puddle	Piles (Driven)	Lumber (in place)	Concrete (Cement)	Granite like Charlesbank.				
Coffer Dams.											
Lock and Boston End.	——	6,720.	18,075.	3,390.	34,424.	——	——	2,785.	——	——	65,394.
Cambridge End.	——	——	5,800	960.	10,480.	——	——	250.	——	——	17,490.
Middle, or Main Shut-off Dam.	——	——	——	4,800.	20,960.	——	——	1,000.	——	——	26,760.
Pumping out Coffers.	——	——	——	——	——	——	——	——	——	——	9,000.
Removal of Coffers.	——	——	——	——	——	——	——	——	——	——	7,000.
Construction.											
Lock Complete. Drawbridge and its Immediate Supports. Power House.	5,070.	5,780.	——	25,780.	20,130.	225,475.	20,720	90,505	2,700.	44,700.	440,860.
Flood Sluices. Two Spillways and Ice Run-offs. Two Sewer Outlets.	4,670.	1,815.	3,110.	10,980.	8,480.	77,550.	10,770.	1,690.	——	13,400.	132,465.
Main Dam.	9,450.	41,865.	35,040.	14,880.	6,276.	1,500.	90,400.	136,055.	——	——	335,466.
Approaches to meet New Grade.	2,480.	619.	9,320.	4,440.	3,455.	28,280.	14,676.	18,860	——	——	82,130.
Pavements and Walks.	——	——	——	——	——	——	——	——	74,385.	——	74,385.
Railings.	——	——	——	——	——	——	——	12,120	——	——	12,120.
Totals.	21,670.	56,799.	71,345.	65,230.	104,205	332,805.	136,566.	263,265	77,085.	58,100	$1,203,070.
Engineering and Contingencies.											120.300
Whole Structure.											$1,323,400.

PROPOSED CHARLES RIVER DAM

Preliminary Estimate of Cost — J. R. Freeman Chief Engineer.

PLAN No. 4. LOW DAM, 100 FEET WIDE, WITH STEEL VIADUCT, WITH CATCH BASINS.

Containing Deep Lock, Retractile Draw, Ice Weirs and Flood Sluices.

Computations by W E Spear and E D. Pingree, Ass't Eng'rs.

Portion of Structure.	Excavation	Earth Fill: Gravel	Earth Fill: Puddle	Lumber: Piles (Driven)	Lumber: Lumber (in place)	Masonry: Concrete (Cement)	Masonry: Granite like Charlesbank	Structural Steel & Iron.	Pavements and Walks.	Power Plant Gates & Machinery	Total.
Coffer Dams.											
Lock and Boston End.	——	6,720.	18,075.	3,390.	34,424.	——	——	2,785.	——	——	65,394.
Cambridge End.	——	——	5,800.	960.	10,480.	——	——	250.	——	——	17,490.
Middle, or Main Shut-off Dam	——	——	——	4,800.	20,960.	——	——	1,000.	——	——	26,760.
Pumping out Coffers.	——	——	——	——	——	——	——	——	——	——	9.000.
Removal of Coffers.	——	——	——	——	——	——	——	——	——	——	7,000.
Construction.											
Lock Complete.	4,080.	5,220.	——	22,176.	19,367.	164,500.	2,840.	24,680.	3,000.	13,600.	259,463
Drawbridge and its Immediate Supports.	——	——	——	——	2,200.	9,000.	——	66,950.	5,900	6,000.	90,050.
Power House.	990.	3,300.	——	5,760.	3.650.	51,975.	10,320.	9,270.	——	8,500.	93,765.
Flood Sluices, Two Spillways and Ice Run-offs. Two Catch Basins	14,300.	2,544.	——	9,528.	10,303	165,055.	9,880.	30,110.	——	23,050.	264,770.
Main Dam.	9,000	39,700.	33,600.	16,320.	7,260.	1,400.	94,600.	120,100.	3,600.	——	325,580.
Approaches to meet New Grade.	2,300.	570.	8,480.	4,080.	3,140.	25.900.	15,600.	100.	——	——	60,170.
Pavements and Walks	——	——	——	——	——	——	——	——	74,335.	——	74,335.
Railings.	——	——	——	——	——	——	——	13,308.	——	——	13,308.
Totals.	30,670	58,054.	65,955	67,014.	111,784.	417,830.	133,240.	268,553.	86,835.	51,150	$1,307,085.
Engineering and Contingencies											130,700.
Whole Structure.											**$1,437,800.**

PROPOSED CHARLES RIVER DAM

Preliminary Estimate of Cost — J. R. Freeman Chief Engineer.

PLAN No. 5.- HIGH DAM, 130 FEET WIDE, TOP AT ELEVATION 38.5, **WITHOUT CATCH BASINS.**

Containing Deep Lock, Retractile Draw, Ice Weirs and Flood Sluices.

Computations by W. E. Spear and E. D. Pingree, Ass't Eng'rs

Portion of Structure.	Excavation	Earth Fill		Lumber		Masonry		Structural Steel & Iron.	Pavements and Walks.	Power Plant Gates & Machinery	Total.
		Gravel	Puddle.	Piles (Driven)	Lumber (in place)	Concrete (Cement)	Granite like Charlesbank				
Coffer Dams.											
Lock and Boston End.	—	6,720.	18,075.	3,390.	34,424.	—	—	2,785.	—	—	65,394
Cambridge End.	—	—	5,800.	960.	10,480.	—	—	250.	—	—	17,490.
Middle, or Main Shut-off Dam.	—	—	—	4,800.	20,960.	—	—	1,000.	—	—	26,760.
Pumping out Coffers.	—	—	—	—	—	—	—	—	—	—	9.000.
Removal of Coffers.	—	—	—	—	—	—	—	—	—	—	7,000.
Construction.											
Lock Complete. Drawbridge and its Immediate Supports. Power House.	5,070.	5,780.	—	26,208.	20,210.	230,900.	28,340.	90,505.	2,700.	44,700.	454,413.
Flood Sluices Two Spillways and Ice Run-offs. Two Sewer Outlets.	5,000.	2,000.	3,200.	11,000.	8,500.	80,000.	12,000.	1,800.	—	13,550.	137,050.
Main Dam.	12,925	54,470.	64,820.	22,504.	9,341.	118,200.	124,200.	1,000.	—	—	407,460.
Approaches to meet New Grade.	2,450.	603.	9,160.	4,368.	3,377.	27,860.	20,100.	—	—	—	67,918.
Pavements and Walks.	—	—	—	—	—	—	—	—	90 515	—	90,515.
Railings.	—	—	—	—	—	—	—	13,296.	—	—	13 296.
Totals.	25,445	69,573.	101,055	73,230.	107,292	456,960.	184,640.	110,636.	93,215	58,250.	$1,296,296.
Engineering and Contingencies.											129 600.
Whole Structure.											$1,425,900.

PROPOSED CHARLES RIVER DAM

Preliminary Estimate of Cost — J. R. Freeman, Chief Engineer.

PLAN No. 6. HIGH DAM, 130 FEET WIDE, TOP AT ELEVATION 38.5 WITH CATCH BASINS.

Containing Deep Lock, Retractile Draw, Ice Weirs and Flood Sluices.

Computations by W. E. Spear and E. D. Pingree, Ass't Eng'rs.

Portion of Structure.	Excavation	Earth Fill		Lumber		Masonry		Structural Steel & Iron.	Pavements and Walks.	Power Plant Gates & Machinery	Total.
		Gravel	Puddle	Piles (Driven)	Lumber (in place)	Concrete (Cement)	Granite like Charlesbank				
COFFER DAMS.											
Lock and Boston End.	——	6,720.	18,075.	3,390.	34,424.	——	——	2,785.	——	——	65,394.
Cambridge End.	——	——	5,800.	960.	10,480.	——	——	250.	——	——	17,490.
Middle, or Main Shut-off Dam.	——	——	——	4,800.	20,960.	——	——	1,000.	——	——	26,760.
Pumping out Coffers.	——	——	——	——	——	——	——	——	——	——	9,000.
Removal of Coffers.	——	——	——	——	——	——	——	——	——	——	7,000.
CONSTRUCTION.											
Lock Complete.	4,080.	5,310.		22,608.	19,447.	175,000.	15,800.	24,685.	3,000.	13,600.	283,530.
Drawbridge and its Immediate Supports.					2,200.	9,000.		66,950.	5,900.	6,000.	90,050.
Power House.	990.	3,300.		5,760.	3,650.	53340.	12,540.	9,270.		8,500.	97,350.
Flood Sluices Two Spillways and Ice Run-offs. Two Catch Basins.	14,360.	2,560.		9,696.	10,378	170,900.	19,540.	30,110.		23,050.	280,594.
Main Dam.	12,840.	48,450.	60,000.	24,000.	10,446.	113,750.	106,700.	1,000.	3,600.		380,786.
Approaches to meet New Grade.	2,300	570.	8,480.	4,080.	3,140.	25,900.	18,300.	100.			62,870.
Pavements and Walks.									74 285.		74,285
Railings.								13,308.			13,308.
TOTALS.	34,570	66,910	92,355.	75,294	115,125	547,890.	172,880.	149,458	86,785	51,150.	$1,408,417.
Engineering and Contingencies.											140,840.
WHOLE STRUCTURE.											**$1,549,250.**

Basis of Estimate of Cost of Marginal Conduits, etc.

Besides the dam, there are other essential requirements and structures forming a part of the project.

Those named as "conditions precedent" (on page 28 of the committee's report) are: —

First. — The removal of the continuous pollution from Stony Brook.

(*a*) The greatest step toward this would be the extension of the new deep main sewer up toward Forest Hills. This can be most cheaply built in connection with the extension of the Stony Brook channel, and it has made a very material advance during the past season. It is being carried along by building it into one of the haunches of the main Stony Brook conduit arch. I am told that it is the fixed policy of the city to carry this sewer and the Stony Brook conduit extension a considerable distance up stream each year; and the chief engineer of the sewer division informs me that in the natural order of things this sewer will be carried ahead far enough within the next two years to drain the territory from which the most of this pollution enters. This sewer construction *must be done*, and done promptly, regardless of whether the dam is built or not, and obviously its cost should not be charged up against the dam.

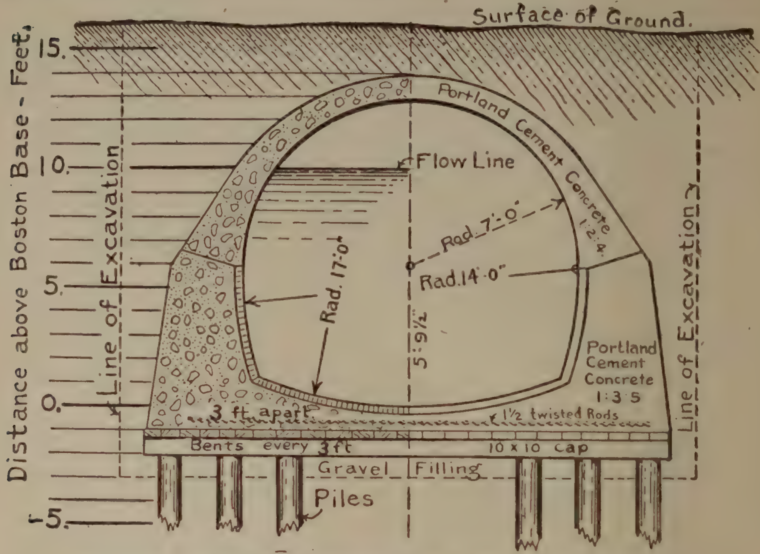
(*b*) Some of the sewers in the Stony Brook district are reported to need radical enlargement or reinforcement by new channels. It is the rapid increase of houses and population in this district, and not the dam, which forces this requirement, and the cost of these new sewers should not be charged against the dam.

(*c*) The old Stony Brook conduit badly needs rebuilding. The cost of this is estimated by the chief engineer of the sewer division at $302,000. The urgent need for this is in no wise conditioned on whether the dam is built or not, for this ancient culvert is reported to have become an unsanitary, tumble-down structure. (See the few typical photographs of its interior, given in Appendix No. 3.) Parts of this conduit were built more than half a century ago, long before the region about it had acquired any of its present characteristics. A series of cross-sections are given in the report of the commission that recommended the new Stony Brook conduit in 1886, that may be referred to in showing how inferior and unstable its type of construction is. Rebuilding this conduit as a storm-water relief channel, and taking out of it the few old sewer connections which continuously pollute the water that flows through it and conveying the discharge from these old drains into the sewer system, will accomplish a much-needed sanitary improvement, which should obviously not be charged against the dam, although the agitation for the dam may have awakened and quickened the demand for it.

A connection at least 400 feet long should be built between the end of the present commissioners' channel and the old Stony Brook gate house, as a means of diverting the dry-weather pollution which makes the Fens basin filthy. Although 400 feet in length can be made to serve for some years, ultimately this should be about 800 feet long, and extend all of the way from the end of the new large brick conduit at Huntington Avenue down to the old Stony Brook gate house.

The cost of this per foot depends on the diameter adopted. If of the very large size shown in section below (probably unnecessarily large, — 14 feet maximum width by 10 feet depth of water), the cost, as estimated by Mr. Cutter, would be, if on piles, $51 per lineal foot, or, for

800 feet, $40,800; or the 400 feet really necessary now would cost about $21,000. If of 12, 10 or 8 feet diameter, the cost would be much less; but whatever size is adopted, the reason for this expenditure is found in making this expensive Back Bay park available for its proper use, as originally planned, and the cost of this should not be charged to the dam.



PROPOSED NEW CONDUIT THROUGH THE FENS, 14 FEET MAXIMUM WIDTH BY 10 FEET DEPTH OF WATER.

TWELVE-FOOT FENS BY-PASS CHANNEL.

Notwithstanding that the Boston park department and the Boston sewer division have repeatedly urged the construction of a conduit about 12 feet in diameter from the end of the new Stony Brook channel at Huntington Avenue down to the Charles River, a distance of about 3,600 feet, at an expense of $300,000 for the channel as proposed by the sewer division, or a somewhat larger sum for the corresponding but slightly larger channel urged by the park department several years ago, I am strongly inclined to recommend that this expenditure be held back, if economy is pressing, and that *first attention be given to the rebuilding of the old Stony Brook channel and the enlargement and extension of the Stony Brook main sewers.*

The old 7-foot conduit will probably serve for a few years fairly well, and carry all of the foul dry-weather flow and the sewer overflow of the small storms and of a majority of all the storms, except the heavy floods of March, when the water is cool and the chance of a nuisance extremely small. With only the 7-foot conduit in use and the dam also in use, a great improvement can be effected over the conditions prevailing in the Fens for five years past.

Whenever this proposed large new conduit for by-passing the polluted Stony Brook around the Fens is built, it is plain that its cost is chargeable to Boston sewer system and to the sanitation and redemption of the Boston Back Bay park, and not to the dam.

Section of Wachusett Aqueduct.

The Beacon Street (or Back Street) Sewer for taking House Sewage.

This (estimated to cost $60,000) is for a matter of common decency, and, while rendered more urgent by anything that makes the Charles basin more attractive, is not fairly chargeable to the cost of the dam.

Second Condition Precedent.

The marginal conduits from the Fens outlet down to the dam, and from the Binney Street sewer outlet down to the dam, are both fairly chargeable to the proposed dam.

The extension of this marginal conduit up to St. Mary's Street was not named as a "condition precedent," although recommended; and its construction can be delayed five or ten years, or longer, perhaps, without seriously affecting the cleanliness of the basin. The completion of the new high-level sewer two years hence will make the discharge very much less in volume than now, and of far smaller degree of pollution than now; and I noted on the inspections of sewer overflows last summer during rain storms that the flow from Muddy River outlet and from St. Mary's Street overflow were much less offensive in appearance than that from the Fens. Mr. Putnam, assistant engineer of Boston park department, tells me that the Muddy River sometimes contains bad growths of algæ, which it would be desirable to exclude from the Charles basin by this conduit extension.

The Boston Marginal Conduit.

The cost of this depends largely on the size adopted, and the size required is largely a matter of judgment. Certain of the most eminent sanitary experts in this country have believed that no conduit at all was strictly necessary. It is obvious that the requirement for carrying capacity is very different from that of the new Stony Brook channel, which was designed to take the entire flow in the greatest storm of half a century. No particular harm can come if this conduit is only large enough to convey all the flood waters of the sewer overflows and of the two Stony Brook channels *in ordinary storms*, while permitting the excess of great and unusual storms, such as come, on the average, only once a year or perhaps the half dozen worst storms in a year; for in these severe storms the proposed conduit would be carrying its whole capacity, and only the surplus, containing extremely dilute sewage, would overflow, and the overflow channels can be placed at such height that the sediment and any floating filth will not escape.

Estimate for Conduit of Same Size as Wachusett Aqueduct.

My own judgment has been that a conduit of the size of the Wachusett aqueduct or the new Weston aqueduct of the Metropolitan Water Board would suffice. The Wachusett is 11.5 feet in extreme width by 10.5 feet in extreme height, and with a slope of 1 in 5,000 would carry 350 cubic feet per second. An idea of its size can be had from the accompanying photograph. An estimate by Mr. Cutter of the cost of this section per lineal foot if built along the margin of the Charles is given below, and makes a total for the 8,900 feet of $422,000; or, including gates and special connections, say $450,000.

This estimate in detail is: —

"Wachusett section" on piles, Charlesgate East to Cambridge Street: —			
Dredging, 120 cubic feet at $0.02,	$2 40		
Piles $\frac{1}{3}$ by 6 = 2 at $4,	8 00		
Cope, $\frac{1}{3}$ by 24 by 8 by $\frac{2}{3}$ = 43 feet at $0.03,	1 29		
Planks, 24 by 4 = 96 by $0.03,	2 88		
Natural cement concrete, 67.5 cubic feet at $0.19,	12 82		
Concrete arch, 21.5 cubic feet at $0.24,	5 17		
Brick lining, 6.67 cubic feet at $0.60,	4 00		
Bulkheads and pumping,	5 00		
Rods, about,	1 00		
	$42 56		
6,700 feet at $42.56,		$285,000 00	
Engineering, etc.,		28,000 00	
			$313,000 00
On platform, in trench, Leverett Street to Cambridge Street: —			
Excavation,	$11 00		
Gravel,	3 00		
Sills,	1 29		
Planks,	2 88		
Concrete (natural),	12 82		
Concrete arch,	5 17		
Brick lining,	4 00		
Pumping,	2 00		
Rods,	1 00		
	$43 16		
Leverett to Cambridge Street, 2,200 feet at $43.16,		$95,000 00	
Extra for piles required, 500 feet, $8,		4,000 00	
		$99,000 00	
Engineering, etc.,		10,000 00	
			109,000 00
Total, Leverett to Charlesgate East,			$422,000 00

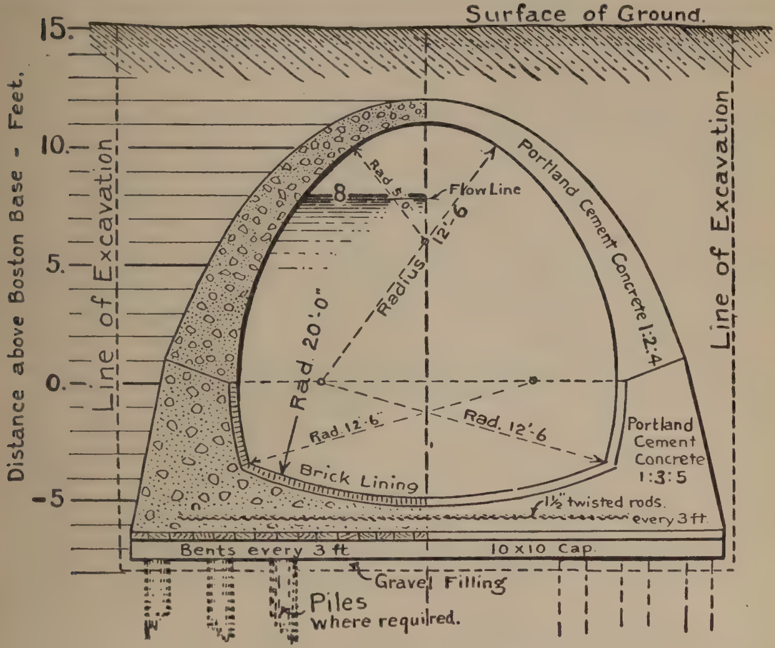
Estimate for Boston Marginal Conduit Sixteen Feet Wide by Thirteen Feet Depth to Flow Line.

For an extremely liberal view of the size desirable for this conduit, I have taken an estimate made by Mr. L. F. Cutter, C.E., based primarily on taking in the entire run-off in all but the most extraordinary storms from all of the area east of the Fens tributary to the Charles, and taking in all sewer overflows between the Fens outlet and the proposed dam, — in all, about 569 acres, plus about 870 acres in Roxbury tributary to the old channel of Stony Brook. The remainder of the water-shed, or an area equivalent thereto, will in the natural order of things go on to the separate system of sewerage before many years, so that its storm water will not be polluted by sewage overflow. This is a district in which the pollution from street wash will probably never be bad.

An elaborate computation of run-off, based on the Chestnut Hill records of rate of precipitation and on the distance of the several districts into which this entire territory is divided from the point of delivery to the conduit, was made by Mr. Cutter, and showed that, with a section adopted capable of conveying 700 cubic feet per second, with a slope of 1 foot in 5,000, *only sixteen storms out of all those in the past fourteen years*, or about one per year, were severe enough to have caused overflow from a conduit of this size; and it is to be remembered that any pollution from overflow in such severe storms would be very dilute.

This estimate gives a conduit much larger than appears to me to be strictly necessary for taking the drainage from this 1,439 acres alone; but the extra capacity would be of value in taking the flood water of the

remaining area of the Stony Brook water-shed and the storm water and street wash now discharging at St. Mary's Street, and would also be of value for the storage of flood water during high tide in moderate storms.



INTERCEPTING CONDUIT
for
CHARLESBANK SECTION
Leverett St. to Cambridge St.

The cost of this large sewer is estimated by Mr. L. F. Cutter, C.E., as follows: —

For Section through the Charlesbank from Leverett Street up to Cambridge Street,

a distance of about 2,200 linear feet, of which it is assumed 500 feet would rest on piles, and that 1,700 feet would rest on ledge or on a platform without piles. Cost per lineal foot: —

Concrete arch, 56.125 cubic feet at 24 cents,	$13 47	
Concrete invert and side walls, 76.82 cubic feet at 19 cents,	14 60	
Brick lining, 7.66 cubic feet at 60 cents,	4 60	
Planking, 100 feet B.M. at 3 cents,	3 00	
Sills, 44.44 feet B.M. at 3 cents,	1 33	
Gravel filling below grade, 34 cubic feet at 4 cents,	1 36	
Rods, 61½ pounds at 2½ cents,	1 54	
Total for masonry per lineal foot,	$39 90	
Excavation, 23 cubic yards at 70 cents,	16 10	
Total per lineal foot on platform without piles,	$56 00	
Additional per lineal foot where on piles,	8 00	
Estimated cost per lineal foot with piles,	64 00	
From Leverett Street to Cambridge Street: —		
500 lineal feet at $64,		$32,000 00
1,700 lineal feet at $56,		95,200 00
		$127,200 00
Add for supervision and contingencies 15 per cent.,		19,080 00
		$146,280 00

For Section from Cambridge Street to Outlet of Fens at Charlesgate, form similar to above; width and slope same as before; height decreased 1 foot by flattening the arch, principally because bottom of this portion averages at higher elevation, rising as it goes up stream. Cost of masonry estimated same per lineal foot as for the above.

Concrete arch, 56 cubic feet at $0.24,	$13 44	
Concrete invert and side walls, 71 cubic feet at $0.19,	13 49	
Brick lining,	4 60	
Planking,	3 12	
Caps,	1 49	
Piles,	8 00	
Gravel filling below grade,	1 36	
Rods in masonry,	1 54	
	$47 04	
Dredging, 150 per lineal foot, 5.55 cubic yards, at $0.50,	2 78	
Pumping,	5 00	
Underdrain,	50	
	$55 32	
Or, say, $56 per lineal foot.		
7,000 lineal feet from Cambridge St. to Fens outlet at Charlesgate, 7,000 by $56,		$392,000 00
Add 15 per cent. for supervision and contingencies,		58,800 00
		$450,800 00
		$146,280 00
		450,800 00
And for the entire 8,700 feet,		$597,080 00

It is assumed that construction would go on in co-operation with filling of narrow strip for marginal parkway, which would serve largely for a coffer-dam, that construction would proceed up stream.

City Engineer's Estimate for Marginal Conduit for Ordinary Storms only, January, 1902.

On page 142 of Appendix No. 2 will be found a quotation from an estimate for a marginal conduit 12 by 12 feet, of horseshoe section, from Fens outlet to location 600 feet above Craigie bridge.

$$\$328,500 + \$90,000 + \$6,000 = \$424,500 + 10\% = \$466,950.$$

Adding a pro rata allowance for the additional 600 feet, we have $501,930 as the cost of a 12 by 12 foot marginal conduit from the dam up to the Fens outlet.

Conclusions, Boston Marginal Conduit. — The construction of this marginal conduit would not be difficult or involve any unusual expense if taken in connection with the building of the embankment or esplanade, mostly about 100 feet in width, authorized by the Acts of 1893, chapter 435.

By first depositing a part of this filling in the cheapest possible manner from scows at high tide, and then driving the piles and setting the platform at about grade 5 for the embankment wall, and then completing this wall to grade 11 and filling any convenient width behind it, — say 50 or 60 feet, — an excellent coffer-dam would be formed, behind which the work could be carried ahead rapidly, and carried on simultaneously at several sections.

Finally, after some further consideration of the appropriate size, I estimated the probable cost of the marginal channel on the Boston side from Leverett Street to the Fens outlet at $500,000.

MARGINAL CONDUIT, BOSTON SIDE FENS BASIN TO MUDDY RIVER AND ST. MARY'S OR ASHBY STREET, — LENGTH, 3,960 FEET.

In the approximate estimate of the city engineer in Boston, made January, 1902, reported on page 142 of Appendix No. 2, it was estimated that a conduit horseshoe section, 12 feet wide by 12 feet deep, could be built for $45 per lineal foot for the 1,300 feet from the Fens outlet to Deerfield Street; and that for a conduit, 7 feet 3 inches inside diameter, from Muddy River outlet up stream to Ashby Street, the cost would be $25 per lineal foot.

2,400 by $25, equals (St. Mary's or Ashby Street to Muddy River)	$60,000 00
1,300 feet by $45, equals (Muddy River to Fens outlet)	58,500 00
	$118,500 00
10 per cent.,	11,850 00
	$130,350 00
Add 260 feet additional length, at $50,	13,000 00
Total (St. Mary's Street to Fens outlet),	$143,350 00

The construction of this part of the Boston marginal channel was not named by the committee as a "condition precedent," and can be deferred five or ten years or longer without serious risk, and can be constructed just about as cheaply after basin is held at grade 8 or 9 as now.

Marginal Conduit on Cambridge Side from Binney Street Sewer to Near Crossing of Lechmere Canal.

Fourteen hundred feet in length of this can be built under very favorable circumstances, through the unfinished park called "The Front."

It is estimated that a "horseshoe" section, 9 feet wide by 8 feet depth, can be built at not exceeding $30 per foot.

1,400 by $30 equals,	$42,000 00
Inverted siphon, 400 feet long, under entrance of Lechmere canal, top 15 feet below mean low water, or 23 feet below proposed water level, circular section, 7 feet 6 inches inside diameter, consisting of a steel shell 9 feet in diameter, ½ inch thick, lined with 8 inches of brick work, to be built in sections above water level on pile supports and lowered into deep channel previously dredged in the blue clay, and then bolted together and covered by blue clay puddle, estimated outside cost $60 per lineal foot in place, $400 by $60,	24,000 00
Connection at Binney Street sewer, including gates and overflow weirs,	4,000 00
Circulating pipes from Broad canal and Lechmere canal, about 800 feet total length, with weirs and flushing gates,	10,000 00
Total,	$80,000 00
Contingencies and supervision, 10 per cent.,	8,000 00
	$88,000 00

Dredging of Ship Channel in Charles Basin.

It will be noted, on examining the large contour map of the Charles River basin, that a pool of ample depth extends up to within 150 feet of the entrance to the Lechmere canal, and that a depth of 13 feet below present low water, which is equivalent to a depth of 21 feet below the proposed basin level of grade 8, extends to within 800 feet of the outlet of the Broad canal. The cost of dredging channels of full depth required for vessels drawing 20 feet up to the entrance of these canals would be very small, and for a channel 200 feet in width would cost, for 45,000 yards, at 30 cents per cubic yard, only $13,500.

Above Cambridge bridge it will be noted, from studying the blue areas on the large contour map of the basin, that channels that will give 16 feet in depth of water can now be found for nearly the entire distance up to Essex Street, Brookline; and only a comparatively small amount of dredging would be required to give a depth of 21 feet up to this point.

It will also be noted that in the report of Mr. F. W. Hodgdon of the Massachusetts Harbor Commission, Appendix No. 12, pp. 421, 426, the estimate to cover the dredging within both the Broad and Lechmere canals to the full depth stipulated by the property owners, *together with* the dredging of channels of the main basin approaching thereto, was estimated at only $39,400.

The material for filling the 100-foot esplanade 1½ miles in length between the Charlesbank and the Fens outlet will naturally be taken from the river bed, just as was done in the filling of the Cambridge flats and in filling a portion of the territory reclaimed from the Charles on the Boston side. To furnish this amount of material will require an amount of dredging vastly in excess of what is needed to give the most ample channel for navigation by ships of 20 feet draft all the way from the proposed dam up to Essex Street bridge. To take this material from the localities most advantageous to navigation will add slightly to the cost that would have to be met if this material were dredged from directly alongside the proposed fill; and, as compensation for this extra length of transportation, I have included the lump sum of $11,500 and added to it the $13,500 just previously estimated, making $25,000.

I believe that the probabilities are that no dredging whatever will be required for the mere purpose of cleansing the bed of the Charles by removing sludge deposits, except over very limited areas near the Fens outlet, near the Binney Street sewer outlet and near the starch factory drain and the abattoir; and these areas can easily be dredged while obtaining the filling required for the proposed esplanade 100 feet wide in the rear of Beacon Street.

Canal Improvements.

The data for estimating the cost of dredging the Broad and Lechmere canals and rebuilding walls will be found in the estimate by F. W. Hodgdon, Appendix No. 12; also in the statement by Albert E. Pillsbury, counsel for the property owners on the Cambridge canal. Although it is estimated by Mr. Hodgdon, on p. 424, that the sum of $40,000 judiciously expended would probably leave the owners of these walls, after the dam is built and the basin held permanently at grade 8, as well off as they are to-day, and also notwithstanding this takes no account of the great betterment that will come to all of these property owners from the deep lock now proposed, which will permit any vessel entering the Charles above the railroad bridge to proceed to its berth irrespective of the state of the tide, I have included an estimate of $100,000 for the improvement of these canals, and the possible damage to some of the canal walls while dredging.

Cost of New Embankment Walls for Charles Basin.

The control of the water level at a nearly constant height of about 8 or 9 feet above Boston city base by means of the proposed dam will effect a saving in the cost of the necessary embankment walls of the upper portions of the basin, and effect a great saving of cost in the sanitary improvement of the present dirty, marshy, mosquito-breeding borders above Essex Street, which together will be more than sufficient to pay for the marginal conduits and their accessories, made necessary by the proposed dam.

A large part of this saving is found in the cheaper type of embankment wall made feasible by the control of the water at a nearly constant level of grade 8 or 9, instead of having to adapt the wall to extreme tides, rising often to grade 13 and sometimes to above grade 15.

With a "Stony Brook flood" coming on top of a "Minot's Ledge tide," thus giving superimposed the two separate most extreme conditions of the past half-century, if the proposed dam is built, the basin level need not rise above grade 11, and the top of the wall may safely be 4 or 5 feet lower than under tidal conditions; and, whereas the bottom of the wall to fit present conditions should be at about grade 0, it need not extend below grade 5 or 6 if the basin is to be at a constant level of 8 or 9, as proposed.

The Charlesbank wall, which cost about $65 per lineal foot, and also the sea wall of the Cambridge Front and the Cambridge Esplanade, are fair examples of what is necessary under present tidal conditions. On the other hand, the design shown in the following drawing will serve excellently if the basin level is controlled by a dam; and this wall can be built for about $20 per linear foot, thus saving about $45, as compared with the Charlesbank wall, and giving a wall much more easily kept clean than the Charlesbank wall.

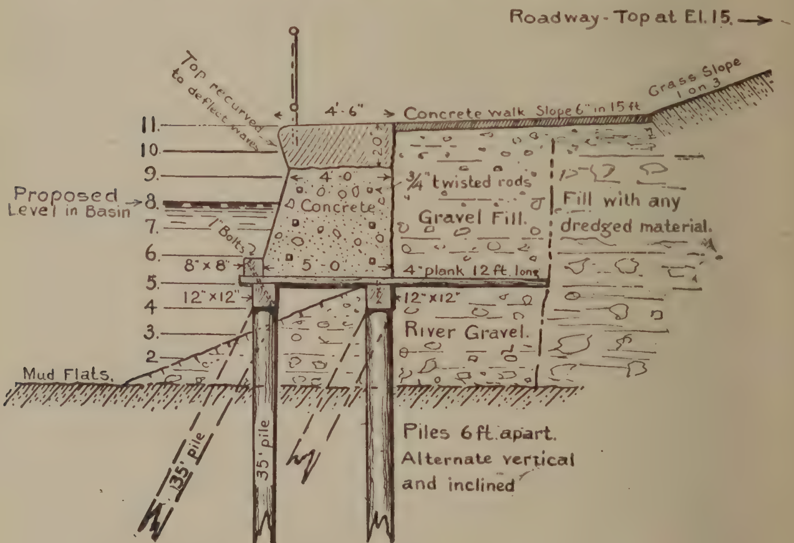
ESTIMATE OF COST PER LINEAL FOOT.

Coping, cut granite, fine-cut top and front joints ¼ inch for 2 inches back from face, 7.5 cubic feet, at $1.10,	$8 25
Concrete, Portland, ⅔ cubic yard, at $7,	4 67
Piles, 4 in 12 feet = ⅓ pile per foot, at $5,	1 67
Caps and fender, 30 feet B. M., at $0.04, including labor,	1 20
Plank, 4-inch Southern pine, 48 feet B. M., at $0.04, including labor,	1 92
Bolts and tree nails,	25
Twisted rods, 11 pounds, at $0.02,	22
	$18 18
Add for contingencies and supervision 10 per cent.,	1 82
Estimated cost per lineal foot,	$20 00

The stone in old wall would be far in excess of amount required to build this wall, but would not lay so smooth a wall as desirable for cleanliness, or so strong as desirable for resisting ice and impact. It could be utilized, however, in various ways, and lessen above cost.

The drawing on the opposite page, from the studies of the Joint Board of 1894, exhibits the great saving in masonry effected by the control of the basin at a constant level.

On the Boston side, in order to carry out the improvement contemplated by chapter 344 of the Acts of 1891 and chapter 435 of the Acts of 1893, and provide an esplanade of about 100 feet in width along the basin from Cambridge bridge up to Charlesgate West, in place of the present unsightly back alley in the rear of the Beacon Street houses (see the large folding map of the lower Charles basin), there will have to be built about 7,550 lineal feet of this wall; and, if of the Charlesbank type, it is estimated to cost $492,000, while, if of design given below, it will cost $151,000; thus the saving in cost of this wall on Boston side alone from Cambridge bridge to the Fens or Charlesgate West, due to the control of water level in basin, will be $341,000.

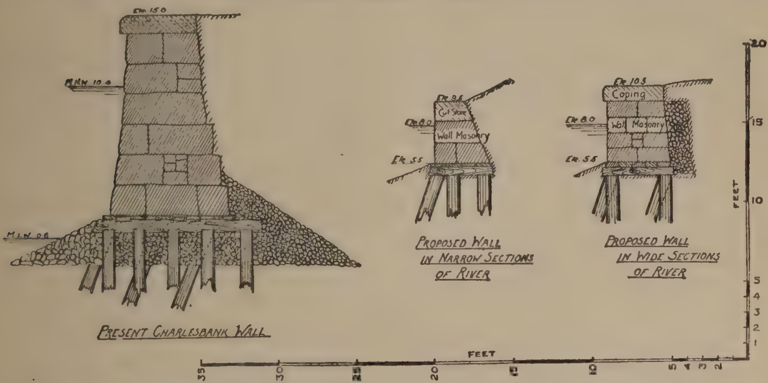


PPOPOSED DESIGN FOR EMBANKMENT WALLS.

The filling behind this wall will amount to about 378,000 cubic yards, which, at $0.60 per cubic yard, will cost $227,000. Because of the space occupied by the marginal conduit and the lower front edge of the embankment, nearly 100,000 cubic yards of filling will be saved, as compared with the old estimates for tidal conditions.

When, in the future, perhaps five or ten years hence, the time comes to extend this esplanade, along with the extension of the marginal intercepting channel, up-stream to Ashby or St. Mary's Street, a distance of nearly 4,000 feet, there will be a further saving. In the absence of borings we may assume that a wall here for tidal conditions would cost

PRELIMINARY DRAWINGS FOR PURPOSE OF ESTIMATE OF COST, MADE BY THE JOINT BOARD OF 1894.



THE ABOVE SHOWS THE DIFFERENCE IN AMOUNT OF MASONRY REQUIRED FOR A SUITABLE WALL, ACCORDING AS A DAM IS BUILT, OR NOT.

much less than the Charlesbank wall, or, say, $45 per foot. If thus saving $25 per lineal foot, the total would be not far from 4,000 × $25 = $100,000.

So far as I have learned, the plans for this improvement are not in shape definite enough for very close estimates for this part of the margin.

On the Cambridge shore, down stream from Essex Street (see evidence, p. 81, also large map of basin), there remain to be constructed, in completion of the plans of the Cambridge Park Commission, about 2,500 feet of sea wall. The Cambridge sea wall designed for tidal conditions for the portion of the embankment thus far built has been much less costly than the Charlesbank wall; but it appears fair to assume that the saving by use of the wall designed for constant level instead of the higher and deeper wall for tidal conditions would be at least $15 per foot, or at least $37,500.

For that portion of the Charles basin above Essex Street the nearly constant water level produced by the dam would also effect a great saving in the cost of the shore improvement, as compared with the cost of improvement under tidal conditions.

Except for the comparatively short portions already improved by the city of Cambridge near the Captain's Island playground, by the Metropolitan Park Commission near the speedway and at a few other points, and by the United States government at the Watertown arsenal, the larger portion of both river banks is to-day in a very unsightly and unsanitary condition, for which before many years the call for improvement will be clamorous if tidal conditions continue.

With reference to the comparatively small portion of the total unimproved shore line that lies within Cambridge, Mr. Geo. Howland Cox, chairman of the Cambridge Park Commission, on p. 81 of the volume of evidence, states that the saving on about 6,440 feet of gravel beach construction would be about $62,000, which is nearly $10 per running foot, or not far from $50,000 per mile.

For the saving in filling to level up the marshy borders so as to remove malarial conditions, Mr. Cox estimates there would be a further saving on the portion of the Cambridge shore line not yet improved, amounting to about $100,000.

Summing up the items of saving already estimated, without yet including the similar saving on the unsightly, unsanitary marshy shores within Newton and Watertown, and exclusive of extension of Boston Esplanade above the Fens, we have the following items of saving: —

Saving on Boston Esplanade wall, Cambridge bridge to Charlesgate only, about	$341,000
Saving on Cambridge Esplanade wall, about	37,000
Saving on Cambridge beach improvement,	62,000
Saving on Cambridge filling of marshy margins,	100,000
Total saving on Boston side below Charlesgate, and on whole Cambridge side due to constant basin level,	$540,000

an amount already approaching the estimated cost of both of the marginal conduits plus the improvements of the Cambridge canals.

Any excess due to contingencies or reasonable damages will surely be much more than covered by the saving in cost of shore improvement and marsh filling for avoiding malarial conditions up through Newton and Watertown, and the saving in the cost of extending the Boston esplanade up stream from the Fens.

When the time comes for extending the Boston marginal conduit up to St. Mary's Street, its entire estimated cost of $143,350 will be offset by the saving in the cost of wall in this distance of about 4,000 feet rendered possible by the constant water level, which saving is estimated at $100,000.

That there are many other items of great economy dependent on the dam in the sanitary development of this large region, for which, from lack of definite plans of improvement, I have attempted no estimate, is plain to any one who will tramp over these marshes and margins of the upper river; and can be also seen in a careful study of the large survey maps of the basin accompanying this report.

There will be a further large saving to Cambridge in the delay in separating sewage from storm water to prevent cellar overflow.

Reviewing this whole matter of cost of the dam and the various public works rendered necessary because of it, the very remarkable fact appears that the cost of this great public improvement of relieving the gorging of sewers in heavy storms at high tide, and substituting a clean, sanitary and beautiful fresh-water lake at constant level, into which large ships can enter and proceed to their berths at any hour, for a fouled tidal estuary in which swift currents and mud banks restrain pleasure boating, and a 10-foot tide ties up the movement of ships for all but a few hours each day, and leaves them lying on the mud at low tide, and in which broad areas of dirty, unsightly mud flats are exposed to the sun at low tide, and whose embankment walls are fouled within the tidal range, — *costs not a dollar more than to continue the marginal improvements and sewer improvements to which the cities of Boston, Cambridge and the metropolitan district are already definitely committed under tidal conditions, without gaining the advantages above named.*

Beach Construction of Metropolitan Park below Arsenal Street Bridge.
View of River at Low Tide, Dec. 18, 1902.

The proposed structure, combining dam and bridge, will cost little if any more than to rebuild the old decayed Craigie bridge, and its cost for future maintenance will be smaller. The marginal conduits cost little if any more than the saving in the cost of certain embankment walls made practicable by the constant water level, and the other improvements in sewer system called for as "conditions precedent" are urgently required, whether a dam is built or not.

A study of the elevations and contours of the marshes and mud flats in Newton, Watertown and Cambridge, shown on the accompanying map of the upper Charles basin, is very instructive, in showing the saving in cost of sanitary improvement of this large region made practicable by the dam.

It is true that, without the dam, the pollution of the Fens basin might be tolerated a few years longer, and that sludge deposits could be allowed to accumulate in the Fens basin five or ten years longer, before they would fill the channel so as to be much more plainly visible, or before they would smell much worse than they do now; that the rebuilding of the dilapidated old Stony Brook culvert might be postponed; that the number of times that such severe storms would occur at high tide as to force overflows of sewage into cellars of dwellings in Cambridge and Boston would not be large; that Craigie bridge, although its timbers are old and rotten, could be patched up to serve with tolerable safety a few years longer; that the expenditure for the Boston Esplanade might be deferred for a long time, except for the marginal conduit, — and it is therefore true that a considerable amount of interest money could be saved by deferring the construction of the dam; but, after reviewing all these matters carefully, it appears to me that the whole sanitary improvements are of paramount importance, and that the whole work should proceed without unnecessary delay.

Appendix No. 20.

Subsidence of Land and Harbor Bottom.

By John R. Freeman, C.E.

Prepared January 1 to May 1, 1903.

Boston is slowly sinking into the Sea, and the Harbor Bottom tends to slowly become Deeper.

All of the territory in and about Boston is probably slowly sinking relatively to the level of the sea. Apparently this subsidence is at the rate of about one-eighth of an inch per year, one inch in eight years, or a little more than a foot in each one hundred years.

This is obviously a question of great importance in comparing ancient soundings with modern, and in considering the possible future shoaling of the harbor.

The present datum plane to which all elevations are referred by the engineering department of the city of Boston, and which is commonly known as "Boston base," probably coincided almost exactly in the year 1830 with mean low water at the Charlestown Navy Yard. Prior to the Miner levels of 1878 the Boston datum had always been supposed to be at mean low water, and was so marked on the plans made by the city up to 1878.*

In 1878 Boston base was found to be about 0.64 below mean low water as determined by the United States Coast Survey at some time just prior to 1870.†

To-day, after the lapse of seventy-two years, this same datum plane, as defined by numerous bench marks on solid ground, according to the best available determinations, is 0.79 foot below mean low water.

This comparison shows that the land now stands about 0.79 foot lower relatively to the sea than it did about seventy-two years ago, and therefore shows that *the land in Boston and vicinity is sinking at the rate of about one foot per hundred years.*

Making a similar comparison on the basis of mean sea level, instead of mean low water, we find the rate of change is 0.71 foot in seventy-two years.

This change affects a very large area, and a variety of independent proofs is offered.

At this rate, the present grade of Atlantic Avenue near the foot of State Street (15.0 Boston base) will be awash by the spring tides of each month about two hundred and fifty years hence.

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* See city engineer's report, 1899, City Document No. 14.
The Miner bench levels of 1878 made the old Coast Survey bench mark 15.33 by Boston base, starting from sundry old benches in the city proper which were found in substantial agreement.
The coast survey report of 1870, p. 93, gives the height of this bench mark as 14.69 above mean low water, 15.33 — 14.69 = 0.64 feet.

† There is some uncertainty in this comparison because of lifting of old bench mark by frost.

The proofs of this subsidence will be presented in detail in the following pages.

These proofs in brief are: —

1. The sills and floor of the masonry dry dock at the Charlestown Navy Yard now stand about 9 inches (0.71 foot) lower relatively to mean sea level than they did seventy-two years ago, while the dock stands at precisely the same level relatively to points on solid ground.

2. The comparison of sundry tide gauges, ancient and modern, indicates progressive subsidence.

3. Many rocks about the edges of Massachusetts Bay are found to be from 1 to 2 feet deeper below extreme low water now than they were about ninety years ago.

4. The extreme tides in great storms appear to show progress toward greater heights.

5. At many points about Boston tree trunks are found standing in salt marsh under conditions that prove a recent subsidence.

I was led to investigate this matter by consideration of statements of Prof. W. O. Crosby regarding the geological causes which had formed Boston harbor, resulting in a submerged valley; and from my observation of the peculiar relation of the present datum plane at present used by civil engineers on the Boston public works, known as "Boston base," to the ancient datum plane of "marsh level" and to "mean low water," and because of the unsatisfactory explanations offered as to why "Boston base" was established at the odd distance of 0.64 foot below mean low water, I was led to investigate the old bench levels.

I had for some years past been interested in the indication of comparatively recent subsidence found in the resemblance of some of our coastal indentations to ordinary valleys that had become submerged, and in studies as to the future water supply of Brooklyn (Report on New York Water Supply, 1889–90) I had occasion to review the proofs of recent subsidence offered by the State geologist of New Jersey, and was therefore the more ready to follow out the indications of the present case.

I found the first definite proofs in a comparison of the oldest recorded mean tide heights at the dry dock at the Charlestown Navy Yard with the most recent tide gauges, and in the difference between the ancient and modern elevation of the coping of the dry dock above mean high water; *originally this distance was* 5 *feet;* now it averages 4.49 feet, and *is now only* 4.37 *feet after allowance is made for lift by frost.**

One reason why the Coast Survey had not discovered this change during their twenty-nine years of continuous tidal observations at the Charlestown Navy Yard is found in the disturbance that the bench marks used by the United States Coast Survey in their tidal observations had suffered because of frost; a second reason in the frequent changes in the location of their tide gauge; and a third in the fact that they reviewed only the observations between 1847 and 1876.

The standard Coast Survey bench mark on the coping of the end of

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* That mean sea level is a better data of comparison than mean high water is indicated by the convergence of the average lines of the Coast Survey groups of tidal observations presented in diagram on p. 568. Apparently by these observations there is a periodic change in mean range of tide.

the dry dock wall was being lifted through a height of about 0.20 foot in these twenty-nine years, while the foundations of the wall and the solid earth throughout this whole Boston region were slowly sinking to the extent of probably 0.30 foot during the same period, and one motion offset and obscured the other.

I was the more ready to explain these discrepancies in the Coast Survey levels as in part due to the lifting of the bench mark on this solid masonry wall, having water on one side and wet earth on the other, because of the experience given in the note below; * and soon found abundant proof of the lifting of these dry dock walls by frost. *The old standard Coast Survey bench mark has beyond all doubt or question lifted nearly* 6 *inches since the wall was built.*

Concerning the Coast Survey Data. — This question of subsidence is a matter on which one would naturally look to the United States Coast Survey for the best information and the highest authority; and it is but fair to say that they have apparently not yet accepted the proof of subsidence that I have so recently presented. It is natural they should proceed slowly and cautiously; but it is, on the other hand, necessary that my report should be promptly brought to a close, for legislative consideration; therefore it appears proper to put the following notes in this record.

It appears to me that the United States Coast Survey has been strangely careless and unprecise in its bench levels in this vicinity, has failed to grasp the conditions affecting its standard of height, and that the experienced officer of the Coast Survey to whom this matter has been recently referred by the superintendent, apparently reached his conclusions without giving reasonable attention to the plain evidence that I presented of the lifting of their old standard bench mark, although this lifting is a matter that should be plain to any engineer or good mechanic who would take the trouble to inspect this wall.

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* *An Example of Increase in Height of a Heavy Masonry Wall alongside of Water.*

I had occasion to make a careful investigation of some discrepancies in supposedly precise levels upon structures connected with the dam and the canal head gates at Lawrence twenty-two years ago, which resulted in positive demonstration that the top of a heavy masonry wall 21 feet in height, founded on ledge and serving as a retaining wall of the north canal, close to the head gates, upon which a monument had been cut in 1847 to serve as a standard for precise levels for use in the building of structures along Lawrence canals, *had progressively risen ⅞ of an inch in the course of thirty-four years,* without any noticeable cracks or other distortions having been produced.

In tracing out the original levels, another excellent monument cut on the solid ledge only sixty feet distant was found thinly covered with earth, which had originally served as a standard, and had been abandoned for more convenient location on the masonry retaining wall. The finely cut crest of the solid masonry dam and the finely cut granite masonry sills of the sluice gates, which were cemented into solid ledge and had never been exposed to frost and were easily reached by emptying the canal, gave excellent independent comparisons, and it was found: —

From 1847 to 1881 the wall bench mark rose by comparison with bench mark on ledge 60 feet distant .071 foot.

By comparison with masonry sills of the sluice gates, which were cemented into channels cut in the solid ledge and had never been exposed to frost, it had risen .08 foot.

By comparison with crest on end of masonry dam it had risen .074 foot.

Other levels were found which proved that in the first two years from 1847 to 1849 it rose .010 foot, and that in the first seven years from 1847 to 1854 it rose .030 foot.

Mr. Richard E. Hale, C.E., principal assistant engineer, Essex Company, at my suggestion, *within the past few weeks,* has made another series of comparisons with the original bench mark on ledge, and finds that in the twenty-two years since my comparisons noted above, it has risen the further distance of .022 foot, so that it now stands .093 foot higher than originally, fifty-six years ago.

After this careful investigation of twenty-two years ago, it was concluded by Mr. Hiram F. Mills, chief engineer, and myself that this rising had doubtless been caused by action of frost on water in the joints of the masonry, which had lifted along many microscopic cracks, and that when the ice had melted fine sand had silted in, thus blocking it from returning exactly to its original position.

After a preliminary study of the situation at the Navy Yard dry dock and the relation of the bench levels, I wrote to the superintendent of the Coast Survey on Jan. 27, 1903, suggesting that a subsidence of the land into the sea would be shown by a careful review of their levels and tide gauges; on February 7 called further attention to a discrepancy of the bench marks and to the swelling of the joints in the masonry wall near these bench marks, shown by the separation of the inlaid copper marks of the old tide staff, and stated that our preliminary review indicated a subsidence of fully half a foot per century; and along with this I called attention to the statements of Professor Crosby as to the strong evidence of a slow subsidence of the region about Boston harbor since the glacial epoch, given in Appendix No. 7, report on Charles River dam, 1903; and also called attention to the statement of Professor Davis of Harvard, in his text book on "Physical Geography," to the effect that the New Jersey coast and Massachusetts coast are probably subsiding at the rate of from 1 to 2 feet per century; and also called attention to the researches of the late State geologist of New Jersey upon the subsidence of its coast.

The superintendent of the Coast Survey very courteously and promptly detailed Mr. H. L. Marinden, one of its most experienced officers (and who it will be remembered testified at the Charles River dam hearings of 1894, pp. 69–103, concerning the shoaling of harbors from the cutting off of tidal prism); and under date of Feb. 18, 1903, Mr. Marinden reports his recent investigations. This report reviews the data on file in the Coast Survey office concerning the various series of tide gauges, refers to the studies of the Boston tides detailed in the Coast Survey report of 1868, Appendix No. 5, but makes no comparison with bench levels from the dry dock to other benches on solid ground, takes no notice of the obvious lifting of the masonry, or the very obvious stretching of original inlaid copper tide staff scales; refers most of the tidal observations to the old bench mark, which I find has risen about 4 inches above the general level of the wall, and is probably nearly 6 inches above its original level, and refers also to a new bench mark established in 1867; speaks of there having been noted in 1857 a settlement of 4 or 5 inches (which there is good reason to believe never took place); and, after reviewing the average results of nearly thirty years of tidal observations, Mr. Marinden concludes: "A digest of the results hereinbefore given shows a remarkable agreement in the elevation of mean sea level at Boston; *no subsidence of the land is indicated*, but rather a slight rise, which probable errors of observation and errors in referring bench marks, etc., may well account for."

I believe that more complete study will reverse this opinion.

Notes on Previous Coast Survey Studies of Change of Sea Level.— Prompted by statements of Professor Shaler that the Maine coast was probably rising, and by statements of some of the old pilots that the rocks and reefs were "growing," Prof. Henry Mitchell in Appendix No. 8 of the Coast Survey report of 1877 discusses this supposed emergence on the coast of Maine, and incidentally reviews many data of the ancient and modern records of the elevation of well-known rocks to low tide. He found good proof that there had been no emergence, and, while some of his data indicate a subsidence, the precision of measurement in the old records is poor, and the rate of movement, if any, not clearly shown. As evidence, these records compiled by Professor Mitchell appear much less valuable than the comparison of the measurements of Nathaniel Bowditch in 1804 with those by Professor Sears in 1894, given on p. 540.

Professor Mitchell's main proof that the coast from Cape Cod to Nova Scotia had not risen is found in the relation of the salt marshes to high tide, — they are flooded now twice each month, as they were three hundred years ago. As to subsidence, he says *this gives no proof, because "new deposits would be made upon the marsh as fast, perhaps, as subsidence took place."*

At Percé Rock, Gulf of St. Lawrence, Champlain, in 1603, said: "At low tide one can go from the main land to said island, which is only some 400 or 500 paces." Description of present conditions, quoted by Professor Mitchell, is not sufficiently exact to show whether this reef may not now be two or three feet lower.

Bulwark Shoal and Dunker's Ledge, off Portland, Me., according to Professor Mitchell, "might be cited in vindication of a theory of subsidence, if confirmed by other testimony." The difference between the height recorded in 1720 and 1874 is nearly 4 feet, but I infer that this measurement was probably crude and happens to exaggerate the change.

The peak of Harding's Ledge, Boston Bay, was reported in 1769 "4 feet out at low water." Boschke, in 1863, found it 3.5 feet out at lowest spring tides. This would show 0.5 foot of subsidence in ninety-four years.

On the Des Barres charts of about 1775 there is some uncertainty whether his datum plane was *mean* low tide or low tide at *spring*, but it has been considered that the latter was most probable. Should it be true that he referred depths of rocks to mean low water, then at Brazil Rock, Jig Rock, Trinity Ledge, all off Nova Scotia, a subsidence of between 1 and 2 feet would be indicated.

Similarly, the Des Barres charts at Great Ledge, Wood's Hole, and Great Ledge, Buzzard's Bay, if his plane was mean low water, indicate a subsidence of perhaps a foot in one hundred and twenty-five years.

While we perhaps gain nothing conclusive from these old charts investigated by Professor Mitchell, they at least *do not discredit a subsidence at the rate of a foot in a century.*

While considering this lack of connection by the Coast Survey between bench marks on the dry dock and bench marks on solid ground, it is of interest to note that it is reported that, in the elaborate series of bench levels made under the supervision of the Massachusetts State Topographical Survey across Massachusetts to Albany, by Mr. C. H. Van Orden, in 1893,* he did not begin his levels at the Navy Yard bench marks, but saved about two miles of levelling by obtaining from the Boston city engineer's office the supposed height of the bench mark on the Museum of Fine Arts, erected on the unstable "made land" of the Back Bay, which is reported to have settled about an inch in the nine years between 1886 and 1895, and had probably settled at least 0.06 between the date it was established and the time when he used it, and started west from this. He is reported to have adopted 5.56 as the height of mean sea level above Boston base.

All Back Bay benches are very uncertain in height, due to the slow compression of the filling under the weight superimposed during the past thirty years, and in some districts this compression is said to have lowered the general surface of the ground nearly a foot. Along some parts of Columbus Avenue the general level of the street is said to have

* It would be interesting to compare this line with the line run across the State by George R. Baldwin in 1828 in the surveys that antedated the first railroad from Boston to the Hudson, and with later railroad surveys, to see if an increase is now found in the anticlinal at the Berkshire Hills. Perhaps it will be found that the early instruments were not sufficiently precise.

been thus depressed about 1.5 feet over broad areas and long distances. This lowering by compression and squeezing out of the water in the earth is a matter entirely distinct from the general subsidence of bed rock and all, with which we are now chiefly concerned.

Scope of the Present Investigations concerning Subsidence. — Notwithstanding Mr. Marinden's conclusion (p. 532), it appeared to me that the evidence of change in the relative level of land and sea was plain, and I have pursued the investigation as diligently as other engagements would permit, studying old maps, old note books and old reports, transcribing and averaging the records of the tide gauges kept recently by the Bureau of Yards and Docks at the Navy Yard, and also transcribing and averaging the tide gauge records kept at India wharf in 1866–67; and have visited Washington, D. C., for the special purpose of personally examining the oldest records of the Navy Department and War Department relative to elevations and tide gauges; and, in general, have sought all available sources of information from which the ancient and recent heights of the tide might be accurately compared.

An investigation of this kind, if exhaustive, is almost never-ending, and I hope to find further note books and records that will limit the margin of uncertainty. Sufficient confirmation has, in my judgment, already been found to justify publishing the matter at the present time, in the hope that this publication will bring in further data and discussion, and that it will arouse an interest in more precise observations in future upon tides and levels in connection with various public works in this vicinity, from which the rate of subsidence can be determined with greater precision; for it is obvious that this matter of subsidence, if an inch in every eight years, is one of the highest importance to engineers in planning works in the vicinity of tidal waters.

The following sources of data have been made use of in this study: —

An examination of all of the oldest maps in the office of the Massachusetts Harbor and Land Commission, and an examination of the oldest note books in the same office.

An examination of Loammi Baldwin's very remarkable engineering library, a portion of which has been recently deposited in an alcove of the beautiful public library at Woburn, Mass.

An examination of the catalogue and of sundry legislative documents in the Massachusetts State Library, State House, Boston.

Conference with United States Engineers' office, Boston, and search for old records therein.

Conference with General Gillespie, chief of engineers, U. S. A., Washington, D. C.

Conference with and search for old records in office of Yards and Docks Department, Navy Yard, Charlestown.

Conference with Admiral Endicott, chief of Bureau of Yards and Docks, Washington, D. C.; examination of earliest plans of Charlestown dry dock on file there.

Search in Bureau of Records, Navy Department, Washington, D. C., for reports relative to the Boston dry dock between 1824 and 1833.

Study of the oldest plans of Boston water works; conference with several of the oldest Boston engineers now living.

At my request, Mr. Loammi F. Baldwin, C.E., who now resides in the old Baldwin mansion at North Woburn, with the consent of Mrs. Griffiths, to whom the Baldwin papers have come by inheritance, has made a search (thus far unsuccessful) for note books and papers relative to the original determination of mean high water or marsh level in some of the many chests of papers preserved by the Baldwin family, now stored at the old homestead.

I am indebted to O. H. Tittmann, superintendent United States Coast and Geodetic Survey, for his promptness and courtesy in detailing assistants Marinden and Shidy to investigate tidal heights.

To the courtesy of Mr. F. W. Hodgdon, chief engineer, Harbor Commissioners, and to Mr. Henry B. Wood, C.E., formerly chief engineer, Massachu-

setts Topographical Survey Commission, for careful levels and measurements of the masonry of the Charlestown dry dock.

To Messrs. F. P. Stearns, chief engineer of the Metropolitan Water Board, and Dexter Brackett, engineer distribution department, for review and comparison of bench levels, ancient and modern, from Beacon Hill and Chestnut Hill to Lake Cochituate.

To Mr. Wm. M. Brown, chief engineer, metropolitan sewers, for a review and analysis of tide gauge records at the Deer Island pumping station, and for a review of the accuracy of their bench levels from old Boston to Deer Island.

To Admiral Mordecai T. Endicott for search among old plans on file in the Bureau of Yards and Docks at Washington.

To F. O. Whitney, city surveyor of Boston, and F. M. Miner, assistant, under whom, years ago, many of the most precise bench levels in Boston were run, for a review of the old notes in their office, and for accompanying me on an inspection of the dry dock and its deranged coping and elongated old bronze tide staffs.

To William Jackson, city engineer of Boston, for a review of old plans, and for detailing Mr. L. F. Cutter to search their records for notes on "tide marsh level" and the establishment of "Boston base."

To Prof. John H. Sears, curator of the Peabody Academy of Sciences, Salem, for his very instructive observations and notes on subsidence.

Proofs of Subsidence.

(*a*) *Subsidence of Dry Dock at Charlestown Navy Yard.* — The coping of the dry dock was completed in 1831, and is shown by a statement on the Perham map of 1836, under the authority of the engineer who built the dry dock, to have been "*supposed to be 5 feet above mean high water.*" This 5 feet is confirmed by figures on several of the original plans of the dock. At the points where least disturbed, this coping is only 4.49 feet above the mean high water of to-day, as shown by the average tide gauge records of 1902; but the coping at this point has probably been lifted by frost about 0.12 foot, so that the subsidence in seventy-two years, judged by high tides only, instead of being 0.51 foot, is more probably 0.63 foot, and the tidal range then supposed to be 10 feet is now more nearly 9.8 feet.

Judging by low tides only, we get a larger rate of subsidence.

The zero of the inlaid bronze scales or "tide staffs," built into the dock walls, is found to be exactly at the level of the sills of the floating gate and of the turning gate of the dry dock; and the old plans state that these sills were built 15 feet below ordinary low water; to-day they are 15.79 feet below mean low water.

Averaging the mean high water and the mean low water by the gauges of 1902 at the Bureau of Yards and Docks recording tide gauge, we find that *the sills and undisturbed foundations of this granite dock now stand* 0.71 *foot lower relatively to sea level than when the dock was first built, seventy-two years ago.*

(*b*) *Tide Gauges at India Wharf.* — The self-recording tide gauge maintained under the supervision of George R. Baldwin, then State engineer, during nine lunar months, from Sept. 13, 1867, to June 4, 1868, referred to "Boston base" by a line of bench levels which was run to tie on to several of the old benches, shows that "Boston base" was at that time 0.34 foot below mean low water; and if, as we have good reason to believe, Boston base coincided exactly with mean low water of 1830, this gives a subsidence of 0.34 foot in thirty-four years.

An average of the self-recording tide gauge maintained by the Bureau of Yards and Docks at the Charlestown Navy Yard for the twelve lunar months from Feb. 8, 1902, to Jan. 28, 1903, carefully referred to "Boston base" by several lines of bench levels, shows that Boston base is now 0.79 foot below mean low water. Comparing this with the

Baldwin determination of 1868 gives a subsidence of 0.35 foot in thirty-five years.

If instead of mean low water we make this comparison on the basis of mean sea level, accepting 5.00 as its distance in 1830, the Baldwin tide gauge gives 5.20 for the distance in 1868, while the Navy Yard tide gauge records of 1902 give 5.71.

(*c*) *Tidal Observations of United States Coast Survey.* — The tide gauges maintained by the United States Coast Survey from 1848 to 1876, after being corrected according to the best available data for the distortion in height of the dock wall, show a change during that period of only about 0.03 foot in twenty years, or from mean sea level at 20.26 by the dock-sill datum for the mean of the first group of observations from 1848 to 1857 this changes to 20.29 by the mean of the group from 1870 to 1876. This concurs with Mr. Marinden's conclusion. But the unfortunate frequent change of location of gauge and the lack of full description of how gauges were set and corrections applied detracts from the reliability of this record.

(*d*) *Change in Relative Elevation of Datum Planes and Sea Level.* — Tide marsh level datum, established prior to 1834 and used in 1848 in the construction of the Cochituate water works, although commonly regarded as 9.91 feet above Boston base, is found, according to the most complete determinations made by the water works engineers, in 1895, to have been 10 feet above Boston base as established in 1854, *which was supposed, by the engineer who ran the levels from the dry dock, to have been established at mean low water.*

The tidal range in 1820–30 was very nearly 10.0 feet; therefore, the inference is almost irresistible that "*tide marsh level*" *was the same as mean high water* at the date when "marsh level" was first established and used for the datum plane. Sundry notes in old survey books confirm this, as will be shown later.

(*e*) In the early descriptions of the dry dock it was stated that there was a depth of 25 feet over its sill at "ordinary" or mean high water, and 15 feet at mean low water; to-day the navy's memorandum blue-prints, for reference in docking, call the high-water depth 25.56 feet, and the corresponding low-water depth with 9.8 feet range would be 15.76.

(*f*) *Progressive Increase in Tidal Height of Greatest Storms.* — The possible value of this particular line of evidence is very small, because of the great variability in strength and duration of wind, and the fact that whether the storm falls in a spring tide or a neap tide period, or at an extra low run of spring tides, may affect its extreme height by more than a foot. Such evidence as there is of height attained by tide in greatest storms, is at least not opposed to the view that there has been a subsidence, and the constant wearing away of the sea bluffs encourages this view.

The only reliable means for determining the rate of subsidence with precision, or whether subsidence is still going on, is by comparison of long series of tide gauge observations, as many years apart as possible.

The rate of subsidence is so slow, and the tide so variable and so affected by strong winds long continued from a single direction, that isolated observations, unless carefully made under normal conditions, with the time and stage of tide well defined, count for but very little in a precise determination. It is not uncommon for a strong easterly wind

storm to raise the high-water mark two feet, or for a long-continued strong westerly wind to depress it at an equal amount. The raising of the general level by 2 feet during a single tide would, of course, raise the mean of the 56 low waters in a lunar month by 0.036 foot. In tidal averages for a long period the effect of the increase from easterly winds will naturally be offset, and nearly or quite obliterated, by the decrease from westerly winds.

It is stated * that Baldwin fixed the height of the dry dock coping *several inches above the highest tide experienced in the sixty years prior to* 1831; and Mr. Baldwin states in his report on the harbor map of 1837 "that during the building of the dry dock on the 26th of March, 1830 (at the culmination of spring tides), the tide rose in a violent storm 1½ *inches above the coping*, and was said to have been the highest known within the memory of man."

The "Minot's Ledge tide" of April 16, 1851, rose to an extreme height of 7 *inches above the top of the coping*. This was also near the time of extreme spring tides.

In the great gale in which the steamer "Portland" was lost, Nov. 27, 1898, the tide at the Deer Island pumping station rose to 14.6, Boston base. Mr. F. W. Hodgdon, after the storm was over, sent out a levelling party to level on flood marks shown around the Boston wharves, and concluded that a fair mean value of the heights pointed out was 15.0, Boston base. This "Portland" storm came on the full of the moon, but at a low run of tides; had the same wind happened at the extreme spring tides of March, April or November, like the storms of 1831 and 1851, the tide would have risen 0.8 foot higher, thereby giving *a progressive increase of height in extreme storms from "several inches" below the level of the coping in the sixty years prior to* 1830 *to* 1½ *inches above the coping in* 1831, *to* 7 *inches above the coping in* 1851, *and nearly a foot above the coping in* 1897 (had the gale been at high spring tides).

Other Evidence of Subsidence.

There are many other indications of recent subsidence found along the coast in the vicinity of Boston, but these do not give the rate with precision, and afford no proof of it being still in progress. The following are the most noteworthy examples: —

(*g*) "*Stump Marsh*" *in Medford.* — On p. 495, of "History of the Town of Medford," by the Rev. Charles Brooke, published in Boston in 1855 by J. M. Usher, the following statement appears: "There are many stumps of large pitch pine trees now remaining in East Medford on land of Charles Hall. This field is called 'Stump Marsh.' At the usual spring tides the salt water covers this field for from 4 to 8 inches in depth. *Could this forest of pines have lived and grown up if thus covered with salt water every fortnight?* † Is proof found here of the theory that the land on the New England coast is sinking?"

(*h*) Mr. Arthur G. Loring of Woburn tells me that in his boyhood, in Medford, forty years ago, these stumps were a well-known object of interest. He also tells me that Mr. Foster, a former ship builder of Medford, told him many years ago that at a point down stream from where his ship yard stood, he, many years ago, found the ways and remains of an earlier and forgotten ship yard covered by a foot of mud, and that there was gravel immediately beneath these ways, indicating that these had originally rested on this as a foundation, and

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* By Prof. G. L. Vose, Trans. Bos. Soc. C. E., Jour. Eng. Soc., vol. 5, p. 18, Sept. 16, 1885.

† The italics are ours.

that the deposit of mud from the tides was comparatively recent, and indicating that the marsh level was higher then than now.

(*i*) *Little Harbor, Cohasset.* — In the town history published in 1898 by Rev. E. B. Bigelow, it is stated on p. 137: "The slow subsidence of our coast has drowned out nearly half of the marsh lands in Little Harbor. The loss sustained by the slow movement of these two hundred and fifty years is clearly seen upon the north side of Cooper's Island (Little Harbor), where 4 acres of swamp meadow were granted to Thomas Barnes and David Phippeny in 1647–48, and where nothing remains of it now above salt water."

"There was a successful scheme which checked this loss by subsidence made in the early part of this (nineteenth) century, when the salt water was kept out by Cuba dam at the site of the present bridge (across the mouth of Little Harbor), and the whole harbor was turned into a fresh meadow. But the pioneers happened along in the nick of time (early part of the seventeenth century), before the sea had submerged the much-needed meadow."

In reference to this apparent subsidence at Little Harbor, a question is raised by Mr. F. W. Hodgdon, chief engineer of the Massachusetts Harbor Commission, as to the probability that even in the earliest days this salt meadow was made available by means of dikes like those built by the earliest settlers around the shores of the Basin of Minas in Nova Scotia, or like those with which the earliest settlers in the Plymouth Colony must have been familiar from their sojourn in Holland.

Notes by Prof. W. O. Crosby.

In response to my request for any items of evidence upon a change in the relative elevation of land and sea that had come under his personal observation, Professor Crosby furnishes the following: —

"In almost any case, the proofs of subsidence are naturally less abundant and less conclusive than proofs of elevation, because, in subsiding beneath the sea, the land carries with it the evidence that it was once above the sea. But for this general principle, the evidence of subsidence would probably be very abundant where now it is meagre.

"In the Boston natural history collection we have wood from a submerged forest on Cape Cod, in the town of Orleans, where it is stated that a forest of stumps may be seen in the clear sea water at a quarter of a mile from shore, but, the antiquity of the wood being unknown, it is, of course, on a par with the submerged peat beds of Boston harbor; that is, it proves, geologically, recent subsidence, but throws no particular light on the rate of subsidence.

Little Harbor, Cohasset.

"In the early history of Cohasset, at that time a part of Hingham, Little Harbor was comparatively a dry meadow, much prized for the crops of hay it afforded; but now it is almost completely submerged by every flood tide, and, considering its landlocked situation, this certainly cannot be ascribed to marine erosion, but affords, to me, satisfactory proof of subsidence.

At Nantasket.

"The area of Straits Pond, at Nantasket, has, I believe, had a somewhat similar history, but is now kept flooded at constant level by means of a dam.

"Nantasket beach, in its older part, is certainly more elevated toward the sea than toward the harbor, and this indicates a subsidence,

since its growth has been chiefly seaward; but in its later growth, being composed of finer material than formerly, the greater elevation across the narrower part of the beach may be attributed partly to sand-dune formation.

At Marblehead Neck.

"At Marblehead Neck, for the last twenty-five years, I have been impressed by what has appeared to me an evidence of subsidence. On the outer or seaward side of the Neck, between Castle Rock and the more southerly promontory known as Marblehead, the sea began, about 1876, to pile up the shingle to a greater height than formerly and to cover the soil and turf, and this has gone on steadily, until now a considerable area formerly covered by grass and bowlders has been washed over, — I should think at least an acre, and possibly more.

"Only two explanations of this have occurred to me: first, the removal by the sea of some off-shore obstruction may permit the waters a freer access to the shore; or, second, it means a subsidence of the land.

At Cohasset Harbor.

"In the salt meadow bordering the branch of Cohasset harbor, known as 'The Gulf,' the roots and stumps of alder trees have been observed beneath 3 feet of marsh mud, and at least that distance below the high-tide level.

At Weir River, Hingham.

"At the mouth of the Weir River in Hingham, on the north side of Rockland Street, cedar stumps can be seen in the meadow which the salt water now overflows.

"Evidence of this sort might be multiplied almost indefinitely.

Indian Shell Heap, Squantum.

"On the shore of Squantum, a short distance south of the causeway of the Moon Island sewer, there exists the remnant of an ancient kitchen midding or Indian shell heap, which was apparently once of considerable extent.

"I have been acquainted with it for many years, and last year, in company with some students, found in it a human skeleton. . . . It is only a foot or two above mean level at the present time, and is being slowly but surely covered by water, although this part of the shore is pretty well protected. . . . The probabilities are that the shell heap extended considerably farther seaward than at present, and I cannot think it probable that it was originally as near sea level as we now find it, especially considering that the part that remains is probably the highest part of the original deposit. . . .

"I am pretty well satisfied that subsidence at an appreciable rate is now in progress, and it does not appear that the large salt marshes are inconsistent with this idea, since they consist, superficially, so largely of vegetable material, and a growth of a foot or two in a century or an inch or two in a decade is quite within the range of probability."

Observations reported by Prof. John H. Sears.

After I had put the preceding notes in form for publication, and had completed most of the comparisons given in the following pages, the following evidence, new to me, was received from Prof. John H. Sears, curator of geological and mineralogical collections in the Peabody

Academy of Science, Salem, Mass., through a reference kindly given me by Mr. Stewart, formerly a civil engineer on the Mississippi River surveys, now in charge of naval records at Washington.

These notes can be found in the Bulletin of the Essex Institute, Vol. 26, 1894, Paper No. 7.

Professor Sears says: "While engaged in other work connected with the geology of Essex County, I have noted such evidences of the subsidence and elevation of the coast line as came under observation, and call attention to them now, hoping to awaken some general interest in this subject. . . . *The evidences of subsidence are clearly shown along the entire coast in many sheltered coves*," etc.*

His most interesting observations noted are those reported on p. 6 of his report, for they indicate the rate of subsidence. He finds, from the comparison of the depth of water over certain rocks in Salem and Marblehead harbors, taken by himself, that *in* 1894 *the depth below extreme low tides was generally from* 1 *to* 2 *feet greater than that given in the report and on the chart prepared by Dr. Nathaniel Bowditch in* 1804–05.

His examples in detail are: —

Bodin's Rock.

Dr. Bowditch reported that the summit of Bodin's rock was 7 feet below low water on the full and change of the moon. Professor Sears found, by soundings taken with an iron rod on this spot, which was easily recognized from compass bearings, that on July 17, 1894, on the full of the moon, low water at 6 A.M. gave 9 feet in depth, or indicated that the rock was 2 feet further below the surface than reported by Dr. Bowditch. A second measurement, on Aug. 1, 1894, new moon, low water at 5.28 P.M., gave 8½ feet of water at the same spot.

"These soundings were made with care, and are reasonably correct, and in this case *offer evidence of a subsidence in the past ninety years, at least, of* 1½ *feet at this point.*"

Privy Ledge.

At the Privy ledge, 300 yards outside Orne's Island, Dr. Bowditch's report gives 5 feet depth at mean low water. Professor Sears found, on Aug. 2, 1894, with a new moon at low water, 5.28 A.M., that there were 7 feet of water at this point, *indicating a subsidence of* 2 *feet*, but says: "There is, in all probability, a greater amount of erosion at this place than on Bodin's rock in the harbor."

Abbot's Rock.

In the shoalest part of Abbot's rock, Salem harbor, Dr. Bowditch reported 6 feet in depth; but Professor Sears found, on Aug. 30, 1894, new moon, low water, a depth of 8 feet, *indicating a subsidence of* 2 *feet.*

Archer's Rock.

At Archer's rock Dr. Bowditch reported 6 to 7 feet of water. On Aug. 31, 1894, at low water, Professor Sears found 8 feet in depth, *indicating at least* 1 *foot of subsidence.*

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* The italics in these quotations from Professor Sears are ours.

Bowditch's Ledge.

On Bowditch's ledge Dr. Bowditch reported 5 to 6 feet of water, where Professor Sears found 7½ feet, *indicating a subsidence of at least 1½ feet.*

Cut-throat Ledge.

On Cut-throat ledge Dr. Bowditch gives 4 feet of water, where Professor Sears "found 6 feet at extremely low water."

Professor Sears concludes: "*There certainly appears to be a considerably greater depth of water on all of those ledges than there was ninety years ago*," and says, of his conclusion: —

"This also agrees with the estimates of Professor McGee, — of 2 feet of subsidence for the century for the entire coast."

The season at which these measurements were taken, "Aug. 30 to Sept. 2, 1894, was one of extreme range of tide," and therefore extreme low water, so that the figures given appear entirely fair, and there is no possibility that Dr. Bowditch could have measured any of these at a materially lower stage.

Professor Sears also gives much exceedingly interesting evidence in the way of submerged tree stumps and peat bogs, *which plainly prove subsidence*, but such evidence *does not measure the rate* of subsidence with any exactness, because of the age of these stumps being unknown.

At Nahant.

He says: "At Nahant the cove between Bass Point and the steamboat landing is covered by from 6 to 13 feet of water at high tide, and, therefore, at from 4 feet above low water to 3 feet below it there may be seen numerous stumps of several species of forest trees. Among those which are well enough preserved to be determined are white pine, white cedar, hemlock, spruce, ash, oak and maple. *The roots of these trees are found in the original leaf mould and peat beds* from 1 to 3 feet in thickness, which rest upon a very tenacious, slippery blue clay of unknown depth, the leaf mould and the peat beds being covered by a washed sand and stones of all sizes in a stratum of varying thickness. There are several other places at Nahant where peat beds are seen at or near low-water mark. One, in the south-west cove of Crescent beach, is quite extensive, and contains many logs and stumps of old forest trees; another, on the north-west side of Little Nahant, is of similar character. Lynn harbor and the marshes of Saugus furnish numerous examples of old peat beds, in which large logs of pine and oak lie embedded below the recent accumulation of marine peat and salt grass roots."

On Beverly Shore.

"On the Beverly shore, between West beach and Moulton's Misery Island, are many stumps of forest trees, which may be seen when the water is clear and still at a depth of 12 or 14 feet at low tide. A piece secured from one of these stumps proves it to be white pine."

At Manchester, Mass.

"In a cove near Chubb's Island, Manchester, at the depth of 11 feet below high-water mark, are the remains of an oak stump, which

now, divested of the sap wood, is 12 feet in diameter inside the buttresses, representing the tree at its full growth in this region. In Manchester harbor, inside of the Ram islands, stumps of white pine and oak are found in the original leaf mould and peat beds, covered by washed sand and rocks, as at Nahant."

At Kettle Cove.

"In Kettle Cove, Manchester, there is one large oak stump 4 feet below low-water mark.

"On Kettle Cove beach a good section of the submerged area is visible at low water during the spring tides. Near the old road bed, inside of Crow's Island, the marine peat and salt grass roots are from 10 to 14 inches thick. Directly under the marine peat is a bed of leaf mould and fresh-water peat, from 3 to 4½ feet in thickness, in which are found numerous logs of pine, spruce and white cedar and the branches of the ground yew, the last named remaining in its normal prostrate position. Below the peat are large oak stumps, standing where the trees grew on glacial drift, showing the subsidence since the bowlder till was deposited in the glacial epoch. While securing a specimen of one of the larger oak roots, scratched pebbles and grooved stones were found with oak roots growing around them in their natural position. From these observations it would appear, —

"First, that the ancient oaks grew in the glacial till, which became depressed.

"Second, that a swamp formed on this area, in which accumulated the peat and leaf mould, upon which grew the pine, cedar, spruce and ground yew.

"Third, that this in turn became submerged, and the marine peat and salt grass formed on it; and, lastly, —

"Fourth, that the seaward slope has become so great that the waves are cutting into and carrying away these earlier formations, and thus exposing them to view."

At Lobster Cove.

"At Lobster Cove, Magnolia, are the remains of numerous red cedar stumps. Red cedar stumps are also found at Mingo's beach, some of which are 6 inches in diameter, only the heart wood remaining. With these are many logs of spruce and hemlock ramified by the borings, and containing shells of *Petricola pholidiformis*, a mollusk abundant in the peat and clay at this beach."

At Mingo's Beach.

Professor Sears presents a photograph of the submerged peat beds, logs and stumps at Mingo's beach, as they appeared in October, 1894; and also presents a photograph of white pine stumps as seen at Pond beach, Nahant, at low tide, in 1894.

Of the peat bed at Mingo's beach, Professor Sears says: "I have collected numbers of wings of water beetles and a great many fragments of other insects which have been identified by Prof. Samuel Henshaw of the Museum of Comparative Zoölogy."

Professor Henshaw in turn says: "I cannot see that the insect remains are any different from what we should find to-day."

The similarity of the trees and of the insects to present species indicates that the submergence is comparatively recent.

At Salem, etc.

"Salem harbor furnishes additional evidence of subsidence; oak stumps are often found on the coast.

"Sunken stumps of forest trees have also been observed at Long beach, Nahant, Little Nahant, Phillips and King's beaches in Swampscott, Marblehead beach, and on the northern end of West beach, Beverly, while the beaches and marshes of Ipswich, Rowley and beyond furnish similar deposits."

"In 1866, Professor Sears reports that he found an area of submerged forests on the cove south-west of Cape Hedge, Rockport, near the point recently called Briar Neck. The stumps, so far as could be determined, were red cedar, pitch pine, maple and birch."

Of these stumps, in his report on the geology of Cape Ann, Professor Shaler says: "These interesting remains lie in a position that appears to me to exclude any other hypothesis than that which assumes that the surface on which these stand has been lowered by the downward movement of the subjacent earth."

Professor Sears further says: "Specimens have been collected from the stumps in many places referred to by me above, and may be seen in the Essex County geological cabinet of the Museum of the Peabody Academy of Science."

Per Contra. — A Caution.

My friend, Mr. F. W. Hodgdon, long chief engineer of the Massachusetts Harbor Commission, urges caution in accepting the evidence of submerged stumps and logs as sure proof of subsidence, *unless located in sheltered coves*, stating that the process of shore wash and undermining by waves may often produce a similar appearance where there has been no real subsidence of the underlying ground.

Nevertheless, I think it plain that many of the foregoing examples are situated where undermining is a wholly unreasonable explanation of the subsidence.

OTHER POSSIBLE SOURCES OF DATA.

The ancient and modern height above mean water of some of the earliest wharves and sea walls might be expected to furnish data, but I have not yet been able to obtain any reliable information from this source.

The earliest records of Middlesex canal and of the Boston & Lowell Railroad have been sought for, in the hope that some reference between tidal heights and existing bench marks could be found, but without success.*

It is reported by the United States Engineers' office that the construction notes of the earliest forts in the harbor do not afford any information, neither do those concerning the lighthouses; and, in general, I have been unable to find any direct evidence earlier than the building of the dry dock which will serve to connect the elevation of existing structures to the tidal planes of the early part of the century with sufficient precision to be of value in the present discussion.

Our most reliable and most precise data are found in the history of the Charlestown dry dock, and, as our investigation has progressed, the evidence found here has been more and more conclusive.

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* A profile of the Lowell Railroad, dated 1836, by James F. Baldwin, gives the bridge over the Charles as at "6.90 above base or high-water mark."

Concerning the Charlestown Dry Dock.

This is our most positive and precise witness, and therefore requires examination at length.

We will review only so much of the history of this dock as has a direct bearing on the permanence of the elevation of the dock, and upon its original relation to the tidal heights.

We have the positive statement, made three years after its completion, by Mr. B. F. Perham, who was one of the engineers engaged in the construction of the dock, and endorsed by Mr. Baldwin, chief engineer of the dock, and chairman of the Survey Commissioners, that its coping as built was "supposed to be 5 feet above mean high water." *

A plan showing the strata excavated, dated Oct. 27, 1829, marked with the initials B. F. P., found among the Baldwin papers, gives the coping at "5 feet above mean high water."

Sundry old plans mark this height as "5 feet above ordinary high water," and sundry old notes of engineers familiar with its construction and the current report of the time indicate that it was commonly understood to have been set 5 feet above mean high water and 15 feet above mean low water.

The most permanent portions of this coping are now found to be only 4.49 feet above mean high water, as shown by the average of twelve lunar months of continuous observation by means of a self-recording tide gauge, in the year 1902.

This cannot be due to change in the range of the tide, for the height of the rise and fall of the tide is now probably slightly less † than in the days when the dock was built. It cannot be due to a settlement in the dock wall, for there is good proof that this part of the coping just referred to is 0.12 foot (or nearly 1½ inches) higher, relatively to the foundations of the dock, than it was when first built, because of the slow swelling of the joints in the masonry under the influence of the frosts of the past seventy-two years; and after deducting this 0.11 foot we find that, had there been no swelling in the height of the masonry, the coping would now stand only 4.37 feet above mean high water, and the change in the elevation of the coping relatively to mean high water is 0.63 foot; and, further, allowing for half of the difference between a mean tidal range of 10 and 9.84, we find that the change in the level of the coping in seventy-two years, relatively to mean sea level, is 0.71 foot.

Precision of Original Determination.

I have been led to regard the words "supposed to be 5 feet," used by Perham in 1837, as merely the cautious expression of a very careful, precise man, and do not regard them as expressing any doubt of the substantial accuracy of this determination; but it is of interest and value to learn with all possible care about the possible margin of uncertainty in this ancient determination of 5 feet. Daily readings on a tide staff for one complete lunar month, in which the heights are not disturbed by strong, long-continued easterly or westerly winds, will give mean high water within 0.2 foot, or ordinarily much closer; and the mean tidal range of 10 feet, figured on all of the early plans, was certainly

* Map of Boston Harbor Survey of 1836, by B. F. Perham, State Library.

† The oldest plans call the tidal range 10 feet. The mean of the first four years (1847–51) of daily observation of the United States Coast Survey makes the range 10.01 feet at the Navy Yard. The mean of twenty-nine years (1847–76) makes it 9.73 feet. The mean of the year's observations of the year 1902 by an automatic gauge makes it 9.87 feet. Any reduction in volume of tidal prism, like that due to filling the Back Bay and the Cambridge flats, tends to lessen the momentum of the current against the Navy Yard location, and thus to slightly lessen the height.

correct within less than 0.2 foot, or probably less than half of this amount at either high or low. In his preliminary report of 1824 Mr. Baldwin refers to a month of tidal observations, October, 1824; but from what I have learned about the building of the dock and the character of its engineer, I have no doubt that tidal observations were continued for much more than a month, and with great care and precision, and I think it probable that they were equal to good determinations of this class at the present time.*

The survey of Boston harbor under these same men, Baldwin and Perham, in 1836, appears to have been more exact than any of the subsequent surveys.

This dry dock was the earliest completed of any government dry dock in the United States. Its construction was carried along almost simultaneously with that at Norfolk, Va., and both were built from substantially the same plans under the same engineer, both having been authorized by act of Congress passed March 3, 1827.

A considerable portion of the report of the Secretary of the Navy, in Congressional Document 143, Nineteenth Congress, March 21, 1826, is taken up by arguments of distinguished naval commanders and others in favor of building government dry docks large enough to serve the largest ships of war of that time; and among these papers, the Secretary of the Navy, Samuel L. Southard, refers to "Paper marked 'E,' prepared by L. Baldwin, who has had an opportunity of inspecting some of the largest docks in Europe, and possesses as large a share of science, skill and experience in works of similar character as any of our fellow citizens." This preliminary report was dated Nov. 6, 1824, and states that it was accompanied by plans.

A diligent search in the archives of the Navy Department at Washington has thus far failed to bring these preliminary plans to light.†

A careful search in the Bureau of Yards and Docks at Charlestown and Washington also fails to discover the full set of working drawings with figured dimensions and details from which the dock must have been built; but a portfolio of early general plans, all beautifully drawn and executed with great nicety of detail (several of them by the hand of B. F. Perham), is found in the Bureau at Washington, on which many features are shown that are of value in the present discussion.

Mr. Baldwin's preliminary report indicates a careful study of the ground by means of borings, and that it was then judged to be hard and stable, and that it was, indeed, at first proposed to found the dock on a timber platform without piles.

Other reports indicate that piles were subsequently incorporated in the design, with a view to securing the greatest possible permanence.

In this preliminary report of Nov. 6, 1824, on p. 22, Mr. Baldwin makes some reference to the height of the tide, *from a register of the tides kept at the yard during the month of October*; but its relation to the dock coping as actually built about seven years later is not given with sufficient precision to serve our present purposes; and it must be remembered that this report of Nov. 6, 1824, was merely a preliminary report; that Mr. Baldwin had then just returned from a year of observation and study of public works in Europe; and it is probable that

* As illustrating Mr. Baldwin's care in such matters, we may note that in 1826, two years before this dry dock was begun, in a letter to Hon. John Pickering, president of the Salem tide-mill dam corporation, Mr. Baldwin says: "The level line for high water at neap tides is at present assumed, because a sufficient extent of the register of tides is not yet obtained to fix with great accuracy the height; it will not probably vary more than 2 or 3 inches from the level taken," etc. Surely Mr. Baldwin would take more care to be precise on this monumental dry dock than for a preliminary report for a tide-mill dam.

† If copies are still in existence, I think it probable that they are filed away among the sixty chests of papers of the Baldwin family at North Woburn.

the tidal question had not been so fully studied in 1824 as it was in the succeeding seven years prior to the completion of the coping.

I have not yet been able to get any description of the tidal records which were undoubtedly taken for defining mean high water, mean low water, etc., during the construction of the dock; but, for further evidence that the builder of the dock was not a man who would leave its height loosely defined, or tolerate the thick joints now found, or tolerate a coping out of level, a brief biographical note is of interest.

Loammi Baldwin.

"No man so well deserves the name of 'Father of Civil Engineering in America' as Loammi Baldwin. Living, as he did, before the days of the railway system and almost before civil engineering was known as a profession, his name is known to very few at the present time, but there is no man among the leaders of industrial work in this country to whom we owe more.

"There were very few works of internal improvement carried out in America in the first years of the present century with which Mr. Baldwin was not connected."

This is the statement of Prof. George L. Vose, at that time professor of engineering in the Massachusetts Institute of Technology, and president of the Boston Society of Civil Engineers, in a paper read Sept. 16, 1885.

Loammi Baldwin, the elder, the father of the builder of the dry dock, was a school-mate, college-mate and intimate friend of Benjamin Thompson, afterwards Count Rumford, and was himself one of the principal proprietors and the superintendent of construction of the Middlesex canal, which extended north from Boston to the Merrimac River, and which, at the date of its construction, was the largest work of internal improvement in the United States.

Three of the sons of the elder Loammi Baldwin achieved distinction as engineers.

James F. made the first surveys for the railroad from Boston to the Hudson River, was a superintendent of construction on the Boston & Lowell Railroad, the earliest railroad out of Boston, and was one of the commissioners for building the first public water supply and bringing the Cochituate water into Boston.

George R. was a particularly fine draughtsman, designed and built the Boston Marine Railway, was consulting engineer for the Charlestown water works, and engineer of the water works for Quebec.

The whole family was thus familiar with that structural work about Boston which was most in need of accurate levels, and the father and each of the brothers had much to do with important work that would cause them to become familiar with the range of the tides.

Loammi Baldwin, the builder of the dry dock, was born in 1780, graduated from Harvard in 1800. In 1807 he visited England, to study important public works; in 1817 he completed the large Boston and Roxbury tidal mill dam, where Beacon Street extension now runs; in 1821 he was appointed engineer of the Union canal in Pennsylvania, 79 miles long, running from near Reading to Harrisburg. About 1824 he spent a year in Europe, studying the docks and public works, and accumulated books that, with his previous collection, formed the finest engineering library then in America.*

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* This library remained in the old Baldwin mansion in North Woburn until about two years ago, when, through the public spirit of Mrs. Catherine R. Griffiths, the daughter of Geo. R. Baldwin, into whose possession it had come by inheritance, about half of it, comprising a majority of the engineering books, was deposited in the public library of Woburn, that it might be safer against fire, and more accessible to students of engineering history.

He was one of the foremost advisers on the construction of the Bunker Hill Monument in 1825; and also, in 1825, as chief engineer, under a request from the Legislature of Massachusetts, studied canal routes from Boston to the Hudson River, and made a report thereon which has been called one of the most complete engineering documents of the time.

In 1827 he was appointed by the Governor of Massachusetts to survey for a railroad from Boston to the Hudson River, and, as already stated, was appointed, March 28, 1827, to locate, design and build the dry docks at Boston and Norfolk. He was subsequently employed by the general government to select a site and prepare plans for the masonry dry dock at the Brooklyn Navy Yard.

With this experience, Loammi Baldwin would have been often called upon to study the range and height of the tides; and the character of his reports show him to have been a man of such habits of precision and thoroughness, and the early drawings of the dock now extant are such models of nicety and precise work, that it is inconceivable that he would build this dock and approve many plans showing the height of the top of its coping to be "5 feet above ordinary high water," or "mean high water," as the plans state it to be, without determining this height by accurate observations.

Several of the earliest and most important of the drawings of the dry dock now on file in Washington were made by B. F. Perham, the same who made the harbor survey of 1836 and the Boston water works surveys of 1835; and these are found executed with great nicety and precision.*

Work was begun on the coffer-dam June 12, 1827. This was completed sufficiently to shut out the tides in the spring of 1828. Bearing piles were driven during the years 1828, and the corner-stone of the masonry laid May 21, 1829. In the report to the Secretary of the Navy, found in Congressional Document No. 2, dated Dec. 3, 1831, p. 254, paper E, is found the following statement: —

"The masonry of the dock may be considered as complete; *the beautiful line of coping* 3 feet wide and 15 inches thick is all laid ere this.†

"The top of the rubble wall behind the coping remains uncovered. It is proposed to cover this with a course of hammered stones, level with the coping, which seems indispensable to protect the backing rubble work from the effects of the frost."

The old frigate "Constitution" was the first ship to use the dock, on June 24, 1833, and the dock was turned over to the Navy Department on Sept. 9, 1833.

It is stated that during the construction of this dock and the dock at Norfolk Mr. Baldwin kept a very full diary, which was lost by the burning of the steamer upon which he was journeying from Norfolk to Boston, in 1834. Mr. Baldwin's residence was in Charlestown, Mass., not far from the Navy Yard.

Mr. Baldwin died June 30, 1838, having been incapacitated for work by a partial paralysis about a year previously.

Use of Dry Dock Coping as a Bench Mark.

It was natural that "the beautiful line of coping" of this dock should be selected as the best and most permanent bench mark in the vicinity

* May 10, 1903. Diligent search by Mr. L. F. Baldwin has just discovered two portfolios of these original drawings among the Baldwin papers at North Woburn, the most of them drawn and colored with a nicety seldom seen in drawings of the present day.

† The stones are beautifully cut, and beyond the shadow of a doubt were originally laid true to line and level, where to-day the outer end is 4½ inches higher than the general average of the coping within 200 feet of the head.

of Boston; that Baldwin and Perham should take it for the datum plane of their soundings; that civil engineers, Thomas Doane of Charlestown and Charles Harris of Boston, should select it for defining their datum planes for their respective cities; that the engineers of sundry schemes for supplying Boston and Charlestown with water in the early days should so use it; and that the United States Coast Survey should adopt it for marking the elevation of its tide staffs in one of the most elaborate series of tidal records that it has ever carried on.

Unfortunately, the dry dock coping, particularly at the outer corner originally selected by the Coast Survey as the reference point for its tidal observations, has not been a reliable, unchangeable bench mark, but has been slowly rising under the influence of frost in the joints of the masonry, until this point on the coping known as the "old bench mark" *is now 6 inches higher, relatively to the foundation of the wall, than it was when the dry dock was first built.* Positive proof of this is found in an examination of the joints between the stones, and in a comparison of the present elevation of the bench mark above the mitre sill and gate sill, and in the relative elevation of the same points as shown in the original plans of the dock. The evidence in detail will be presented later.

In a foot note at the beginning of this paper I have described another instance of the slow increase in height of a wet masonry wall under the frosts of many winters.

Proof that the Side Walls of Dry Dock have increased in Height.

A brief inspection, when the dock is empty, makes this plain beyond question, and there are four separate, distinct and positive lines of proof.

(*a*) *The Coping is now out of Level.* — The earliest published descriptions and the earliest plans concur in showing that the top of the coping was level; to-day the outer end, where most exposed to the water, and where the wall is most nearly vertical, is 4 inches above the level of the inner portion, where the projection of the altar steps gives a chance for the swelling of the lower joints to find relief in tilting the steps without lifting the wall as a whole. *Notwithstanding that the coping stones are thus out of level, the courses of stone at the bottom of the same walls are level.* This excess of height occurs mainly between the quoins of the former turning gates and the extreme outer end of the wall, and can be plainly seen by sighting along the top. It curiously happens that the portion originally selected for the Coast Survey bench mark has been lifted above the general level the most of any part of the wall, and is now certainly 6 inches higher, relatively to the foundation, than when the wall was new. And it is also curious that the various surveyors and hydrographers did not notice what was going on.*

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* ***Corrections of Some Statements about Tide Heights that have been accepted as Authority.***

In the memoranda on standard bench levels sent from the Coast Survey office to C. H. Van Orden, April 17, 1893, and copied and relied on as authority on the relation between Boston base and sea level in the Massachusetts Harbor Commissioners' office, in the Boston city engineer's office, in the Bureau of Yards and Docks at Charlestown Navy Yard, and in the engineer's office of the Metropolitan Water and Sewerage Board (each of these offices independently sent me a copy of this same letter in response to my request for information on this point, and it therefore is worth while to review its lack of accuracy), it is stated: —

"For *about twenty years* from June 1, 1847, high and low waters were *read from a fixed staff made by inserting pieces of copper* into the face of the granite sea wall on the south side of the entrance to the dry dock at the Charlestown Navy Yard."

(Other information indicates that this period was *only ten years*, and that the point of observation was then moved to a point about 400 feet easterly. It is also doubtful

(*b*) *The Side Walls are now Several Inches Taller than shown on Original Plans.* — The earliest published descriptions and the earliest plans show that the top of coping was precisely 30 feet above the level of the inverted masonry arch, the mitre sill and the sill of the floating gate, all of which were on a level.

Careful recent levels, made under my supervision, checked independently by Mr. H. B. Wood, C.E., of the State Harbor Commission, and by Mr. F. M. Miner, C.E., of the city surveyor's office, show that the *outer end of the coping at the Coast Survey's "old bench mark" is now* 30.47 *feet above the gate sills*, and that nearly all of the coping of both sides within 250 feet of the head of dock averages about 30.12 feet above the level of these sills, instead of 30 feet, as shown by the plans.

(*c*) *Joints in Masonry have opened.* — Many of the uppermost stones are now found badly thrown out of alignment; some, apparently, by action of frost in expanding the clay backing, others by the freezing and expansion of water that has entered the joints.

Many of the exposed joints in the side walls are now $\frac{3}{4}$ of an inch thick, and they vary from this down to about $\frac{1}{4}$ or $\frac{5}{16}$ inch, which was apparently the original thickness. Some of the joints have plainly been re-pointed, and many of them are all out of harmony with the general quality of the stone cutting.

In strong contrast with these joints seen in the side walls are the joints in the bottom and near to the bottom, which are of the regularity and thickness ordinarily found in the very best work.

This lifting has occurred chiefly next to the inner face of the dock, and has tipped most of the altar steps back slightly. Mr. Hersey, docking master, who has been employed at this yard off and on for more than fifty years, is confident that years ago these steps were much more nearly level than now.

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if the readings were taken from so coarse a graduation as these bronze marks 1 foot apart afford, and the lowest of these marks is the 16, which is 2 feet or more above the lowest neap tide level.

One would, in the present absence of exact information, think it more probable that a temporary scale or painted board marked to tenths of feet was used, and it is doubtful whether it was set to register exactly with the top of the wall, assumed at 30, or with the average of the bronze marks between 15 and 25, supposing the joints had begun to stretch and to swell the scales.)

"In 1867 a self-registering tide gauge was set up and kept running for about ten years. A porcelain or enamelled iron tide staff was put up in 1870, and adjusted so that its readings were exactly 10 feet less than those of the other staff. Various other staffs were used at various times, but *they were all set so as to agree with the copper marked staff* on the sea wall."

The copper marked staff on the sea wall does not now even agree with itself; its 29 foot mark is 13.35 feet above its 16 foot mark; its 25 foot mark is 9.25 feet above its 16 foot mark. What part of the old "copper marked staff" were all these staffs set to agree with?

"The old bench mark is the top of the granite wall on the south side of the entrance to the dry dock directly over the copper marked staff, on which scale it corresponded originally to 30 feet. This wall settled and had to be repaired from time to time. Our record of these changes is unsatisfactory. The latest information gives this bench mark as about *half a foot less in* 1870 *than in* 1847."

This last statement is simply incredible; *it was probably* 0.13 *foot higher in* 1870 *than in* 1847. I can find no evidence or record to support the view that the wall ever settled. Certainly the sill of the floating gate close to it has never been repaired, and is not now found settled. Certainly the wall has been repaired, but, so far as I can learn, the repairs consisted in re-laying the coping and one or two stones beneath, in repointing open joints, and in replacing one or two cracked stones by means of a floating shield or "coffer-dam" pressed against the face of the wall.

In notes kindly compiled for me from the archives of the tidal division of the Coast Survey office it is stated: —

"July 9, 1857, the observer reports 'The wall of the dry dock has settled 4 or 5 inches.'"

This now appears wholly incredible.

"The new bench mark was established in 1867. It is the top of the facing of the dry dock on the west side, near its head, directly over the foot of the long steps. The

(*d*) *Scales of Feet have been stretched.* — Near the faces of the dry dock are six very substantial tide gauges or scales cut into the masonry for measuring the height of the water on the outside and the inside of the dock. These are graduated in feet, and the feet are marked by bronze castings inlaid into grooves chiselled into the face of the stone. Inspection shows that neither care nor expense was spared in the effort to provide a permanent marking. They are in keeping with the character of workmanship throughout the dock, and that they were put there when the dock was built is indicated by one of them being shown on an original drawing of the dock on file at Washington, in the Bureau of Yards and Docks, entitled "Dry Dock at Boston Navy Yard, drawn by J. Roby, B. F. Perham."

By the scale of the drawing just mentioned the zero of this graduation was at the sill of the gate. This would be the natural zero plane for all such scales, in order that they might show the depth of water over the sill to the master of a ship about to enter the dock.

We now find that, wherever two of the adjacent foot marks are cut into the same stone, they are precisely 1 foot apart, but, excepting near the bottom, wherever a joint intervenes, this distance between the marks is increased, often by ½ or ¾ inch. The present elevation of each mark on these scales, as determined by careful levels and measurement by steel tape, is given in the following table. The marks in the lower 10 feet and the upper 2 feet were measured to with precision, and exact within .01 foot or less; some of the intermediate marks

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spot is designated by an arrow head cut in the stone. *The bench mark was* 0.65 *below the old bench mark as it was in* 1847, and 0.15 below its position in 1870."

I have not seen the slightest reason for believing that the new "bench mark was 0.65 below the old bench mark as it was in 1847."

"Old bench mark above zero of copper scale *of* 1870, . . . 30 feet."

This scale (more probably bronze than copper) is pictured on the old drawing of end elevation of the dry dock, found in the office of Yards and Docks, Navy Department, Washington, drawn by Roby and Perham, and which shows that this was a scale of about 1832, not "*of* 1870."

A full-size detail drawing for these bronze figures has been found among the Baldwin papers, proving them a part of the original structure.

The old bench mark is now 30.47 feet above the common zero level of all of these 6 bronze scales. In 1870 the bench mark and the 30 mark were probably about 30.22 feet above the zero.

"Mean low water (in 1893?) on copper scale of 1870, . . . 15.33 feet."

The mean low water, 1848–65, first reduction, as given on p. 81, Report United States Coast Survey, 1868, is 15.25; and by the second reduction, 1848–66, inclusive, is 15.26. The 15-16 marks on the scale are now (1903) 0.11 foot too high above sill; in 1870 they were probably 0.05 too high; so this should be 15.31, if actually read on the bronze scale. The swelling of the joints is almost wholly above extreme low water.

The 15.33 is deducted from 30, giving 14.67 as the height of old bench of 1870 above mean low water; and deducting 0.15 more for excess of height of old bench above new bench in 1870 gives 14.52 for height of "new bench" above mean low water in 1870, and deducting 4.90 for semi-range of tide gives height of new bench above mean sea level in 1870 as 9.62.

This fails to recognize the error in length of scale. The expansion between the 15–16 marks, low water, and the 25–26 marks, high water, is now (1903) 0.25 foot; probably in 1870 it was about (see curve on p. 555) 0.11 foot; and the top of the wall at old bench in 1870, instead of being at 30, was probably at about 30.21 by the original scale of heights, or dock-sill datum.

Therefore, if these readings of tide height were actually taken by the bronze marks and figures, which there is great reason to doubt, particularly for the period after 1857, and if the mean heights, by the series from 1847–67, were: high, 25.13; low, 15.33 (which values differ slightly from those given in Appendix No. 8 of Coast Survey report for 1868, these being 25.05 and 15.25, or 0.08 less); and since, for the mean of the period 1848–66 inclusive, the new bench was probably .03 above its original height, the 15 mark on scale .03 high and the 25 mark .09 too high, the most probable values relative to the sill and the zero of these scales are mean high water $\left\{ \begin{matrix} 25.13 + .09 = 25.22 \\ 25.05 + .09 = 25.14 \end{matrix} \right\}$ — mean low $\left\{ \begin{matrix} 15.33 + .03 = 15.36 \\ 15.26 + .03 = 15.29 \end{matrix} \right\}$ Range 9.85, mean sea level 20.28 or 20.20, according to which statement of observed height is used.

were hard to reach with the means at hand, but are probably measured correctly within .02 foot.

Several series of levels were run between the new bench mark and the bottom of the dock while the water was entirely pumped out, the bottom of the dock meanwhile sustaining the weight of the cruiser "Nashville."

Levels were taken at twelve points upon these sills, in the middle, at the sides, and at intermediate points, and levels were also taken upon the up-stream end and the down-stream end of the invert of the great arch behind the former turning gates.

It was evident, from an inspection of the original plans and an inspection of the dock and by our measurements, that all of these points were intended to be at the same level; and our measurements show that they are now at the same elevation within about ½ inch. There is a slight crowning found near the centre of the dock along the sill of the floating gate, and also along the mitre sill, that probably has come from the upward pressure while the lock is empty.

These measurements were plotted upon a diagram and a mean line drawn. This line was found to coincide within about ¼ inch of the zero of all four of the bronze tide gauges inside the dock, while with two of these scales this average sill level coincided exactly, within the limits of measurement. It is thus plain that it was the intention to set the zero of all of these gauges at the same level as the sills of the dock.*

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* *Dock-sill Datum.*

This mean line found by the diagram was used for the datum from which to reckon the elevation of the bronze foot marks of the six tide staffs built into the dry dock given on p. 553. Its distance above or below the several points used in defining it is given in the following table. Its elevation relative to the foundations of the dock and the solid ground probably does not differ more than say 0.01 foot, or at most 0.02 foot, from the original level of these sills, and it may be regarded as a very close reproduction of datum by which the dock was built and its gauges set. These sills were doubtless level when first built.

In drawing the average line, I considered it most probable that a very slight distortion had occurred, in which the central portions of the sills had been lifted slightly (perhaps 0.025 foot), by the buoyancy of water and the slightly yielding bed of clay, while close to the walls the excess of weight had caused a slight settlement (perhaps .015 foot), and that near the extreme outer end of the dock a further settlement of perhaps 0.03 foot has occurred. (In Thomas Doane's levels of 1851 he found the coping at extreme outer corner of dock 0.04 foot lower than a point near head, but I do not attach much significance to this.) The lowest marks of the scales themselves were given much weight in fixing this line.

Heights above Mean Line adopted as defining Dock-sill Datum.

DESCRIPTION OF POINT LEVELLED UPON.	Sill of Floating Gate, at 1 Foot inside Face of Gate.	Sill of Former Turning Gates at 1 Foot inside Face of Gate.
	Feet.	Feet.
At about 2 feet from westerly side,	—0.049	—0.011
At about halfway from centre to westerly side,	—0.016	+0.024
At centre,	—0.005	+0.039
At about halfway from centre to easterly side,	—0.025	+0.026
At about 2 feet from easterly side,	—0.038	—0.015
Invert of "great arch" near outer end,	–	+0.033
Invert of "great arch" near inner end,	–	+0.014

Zero of bronze scales above mean line as adopted:—

	Feet.
C, just inside floating gate, westerly side,	0.00
D, just inside floating gate, easterly side,	0.01
E, just inside turning gates, westerly side,	—0.02
F, just inside turning gates, easterly side,	—0.01

The main sill level as determined above was found to be 30.120 feet below the standard "new bench" over the arrow cut.

We thus find that the sill of the dock is 30.12 — 14.52 = 15.60 feet below the mean low water datum plane used by the Harbor Commission; and that it is 30.12 — 15.12 = 15.00 feet below Boston base, as defined by the mean of numerous lines of levels from the solid ground in old Boston.

It is of interest to note the close agreement of the latter figure with the 15.00 feet at which Boston base was originally established by Mr. Harris in 1854, below his point on the coping at the head of the dock, and which at that time must have been almost exactly 30 feet, or perhaps 30.02 feet, above the sill.

One of the best definitions that could be given to "Boston base" would, therefore, be the statement that it is a datum plane 15.00 *feet above the average height of the sill of the Charlestown dry dock.*

That was certainly its relation (± .04) *fifty years ago, was probably its relation seventy-two years ago* (*marsh level* — 10 *feet*), *and certainly is its relation to-day.*

The following measurements were taken to different marks of the old bronze scales, and give the height of each mark above the mean level of the sill, which was the zero of the scale: —

Actual Elevation of Graduation Marks of Old Gauges or Tide Staffs, built into the Walls of the Dry Dock at Charlestown Navy Yard above the Average Level of the Gate Sills and the Average Datum of these Gauges. — From Levels and Measurements under Supervision of J. R. Freeman, February, March and April, 1903.

FOOT MARK OF GAUGE.	GAUGES ON ENDS OF WALL OUTSIDE OF FLOATING GATE.		GAUGES JUST INSIDE OF FLOATING GATE.		GAUGES INSIDE OF FORMER TURNING GATES.	
	A Near South-west Corner at Old Bench Mark of U. S. Coast Survey.	B Near South-east Corner.	C Westerly Side.	D Easterly Side.	E Westerly Side.	F Easterly Side.
30 (top of coping),	30.47	30.36	30.42	30.40	30.33	30.34
29, ...	29.47	29.35	–	–	29.33	29.32
Excess at joint, .	.06	–	.00	.03	.02	.01
28, ...	28.41	No marks.	28.42	28.37	28.31	28.33
27, ...	27.41	New stone.	27.42	27.36	27.32	27.33
Excess at joint, .	.05	–	.01	– .03	.01	.02
26, ...	26.36	26.31	26.41	26.33	26.31	26.31
25, ...	25.36	25.32	25.41	25.33	25.31	25.31
Excess at joint, .	.07	–	.00	.01	.00	.03
24, ...	24.29	24.26	24.41	24.32	24.31	24.28
23, ...	23.29	23.26	24.40	23.32	23.31	23.29
Excess at joint, .	.04	–	–	–	–	.00
22, ...	22.25	22.24	Where record is not given, measurements were not taken.	Where record is not given, measurements were not taken.	–	22.29
21, ...	21.25	21.24			–	21.29
Excess at joint, .	.06	–			–	.07
20, ...	20.19	20.20			20.19	20.22
19, ...	19.19	19.20			19.19	19.22
Excess at joint, .	.04	–			.07	.04
18, ...	18.15	No marks.			18.12	18.18
17, ...	17.15	New stone.			17.12	17.18
Excess at joint, .	.04	–			.01	.05
16, ...	16.11	16.15			16.11	16.13
15, ...	–	–			15.11	15.13
Excess at joint, .	–	–			.03	.03
14, ...	No marks. Below lowest tides.	No marks. Below lowest tides.			14.08	14.10
13, ...					13.08	13.09
Excess at joint, .					.02	.01
12, ...					12.06	12.08
11, ...					11.04	11.08
Excess at joint, .					.02	.04
10, ...					10.02	10.04
9, ...					9.02	9.04
8, ...					8.02	8.03
Excess at joint, .					.02	–
7, ...					7.00	–
6, ...					5.99	–
5, ...			5.02	5.01	4.99	5.00
Excess at joint, .			–	–	–	–
4, ...			–	–	–	3.99
3, ...			–	–	–	2.99
Excess at joint, .			–	–	–	–
2, ...			–	–	–	1.99
1, ...			1.00	1.01	0.98	0.99
0 (not marked), .			.00	.01	—0.02	—0.01

From these measurements, presented in the foregoing table, it appears certain that the top of scale A is about 0.47 foot higher above this zero point than it was originally; and similarly that scale B has been

lengthened 0.36 foot in its height of 30 feet; and similarly that the sill at scales C and D has swollen in height 0.42 foot and 0.40 foot; while at scales E and F the wall had swollen 0.33 and 0.34 foot in height.

It also appears that, at the head of the dock in the immediate vicinity of the new bench mark, the top of the coping is, in all probability, 0.12 foot higher above the bottom of the dock than it was when first built.

No more positive and conclusive proof of the swelling of the side walls and the lifting of the coping could be asked for than is given by the present measurements on these six remarkably well-built tide gauges of bronze castings inlaid in the masonry.

Progressive Lifting of "Old Bench Mark," as compared with "New Bench Mark."

These bench marks are simply the general level of the top surface of the finely cut granite coping at points selected near the outer corner of dock and near its head; no "monument" marks were cut on the stones.

The point known as the "old bench mark," located over the inlaid bronze scale at the south-west corner of the dock, was selected for the standard Coast Survey bench mark by Lieut. C. H. Davis, probably about June 1, 1847, and its height was then taken to be 30 feet, as given by the old inlaid bronze figures.

The dock had then had only fourteen years' exposure to frost, was still practically new, and probably the freezing of water in the joints had not yet done serious injury to them or caused the coping to lift at so rapid a rate as afterward.

From diagram given on p. 555 it appears reasonable to assume that the coping, at this time, had not lifted more than .07 foot at this point.

The point on the coping selected for a new bench mark by Capt. A. C. Mitchell in August, 1867, was close to the head of the dock and on a part of the wall less likely to disturbance, because of the massive projecting courses of the timber-slide and the steps of the altar. This is the point marked by the arrow cut into the vertical face of the wall, and has apparently ever since been called the "new bench mark," and used as a standard by the Coast Survey, the city engineer, the engineers of the Harbor Commission and the engineers of the Bureau of Yards and Docks.

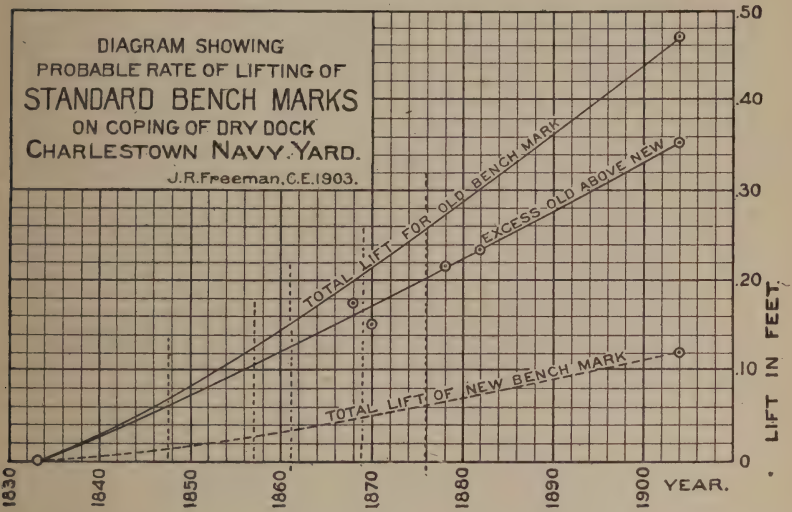
It is to be kept in mind that this new bench mark is on a part of the wall that was rebuilt about 1859, when the dry dock was lengthened.

We have the following comparisons of elevation between the old bench mark and the new. They are very instructive, as showing the regular and progressive character of the change in height.

AUTHORITY.	Old Bench higher than New.
	Feet.
June, 1868, United States Coast and Geodetic Survey,	0.176
Feb., 1870, United States Coast and Geodetic Survey,	0.155
1878, F. M. Miner, city survey office, Boston,	0.210
1882, Gilbert Hodges,	0.230
1903, F. M. Miner,	0.340
1903, W. E. Spear,	0.340
1903, H. B. Wood,	0.370

While we see that the old bench has lifted 0.185 foot (or $2\frac{1}{4}$ inches) since 1868 more than the "new bench," it must be remembered that the new bench is now 0.12 foot higher than originally, and this lifting of the new bench has doubtless progressed proportionately during this time, the main cause of the lifting at both bench marks being the freezing of water in the joints between the stones; but with the relaying of the coping stones some breaks in the line doubtless occurred which we cannot now determine. In the case cited on p. 531 the rise was progressive and long continued.

The relation of these heights to the time elapsed since the opening of the dock is shown by the following diagram: —



Foundation of Dry Dock has not settled.

Having found that the coping of the dock, and more especially the sills and floor of the dock, are lower relatively to sea level than they were seventy-two years ago, it will be natural to ask if the dock itself may not have settled down into the underlying clay, through a distance of 9 inches.

I am convinced that the dock has not settled appreciably. The downward pressure per square foot imposed on the substrata by the dock is small in comparison with the majority of building foundations, for its weight is spread over a very large area, and its height above the original surface is not excessive. Indeed, much attention has to be given to overcoming the buoyancy of a dock when pumped out, and I am told it is the practice to keep this dock wholly or partly empty most of the time.

When reckoning the weight on the platform at the bottom of the masonry, we must remember that this masonry, in large part, merely takes the place of the original bed of heavy sand, gravel and clay that was dug out to the average depth of about 18 to 20 feet.

In his treatise on the naval dry docks of the United States, published in 1852, Gen. Charles B. Stuart, the chief engineer under whom the New York dock was completed, says of the Charlestown dock that, in

preparation of the site, first "18 inches of marsh mud were excavated, then 5 feet of blue clay, then 13 feet of yellow sand and gravel mixed with large stones, then hard blue clay to bottom of foundation pit.

"The piles were driven 3 feet apart on centres each way, but were very irregular in their length until hard pan or rock was reached; in some instances piles would reach rock in 8 or 10 feet, in others they were driven to 30 feet, all, however, reaching firm bottom.

"Depth from coping to mitre sill is 30 feet; depth of water at ordinary high tide over mitre, 25 feet. Broad altar at bottom shows 15 inches in rise at foot of chamber, and corresponds with level of floor at the head."

In the album of original drawings at Washington, sheet No. 4 shows the stratification of material excavated, and indicates that this sloped downward going seaward.

The character of the ground for foundation is much better than around the most of the Boston water front, for it is close to the seaward slope of the Bunker Hill drumlin.

In one of Baldwin's early reports it is implied that piles were not proposed at first, and now with these many piles driven to rock or hard pan the load per pile is so very moderate that appreciable settlement may be regarded as impossible.

Considering that the records on file in the Navy Department show an inclination of the strata of clay and gravel sloping downward toward the sea, and considering the statement as to the varying lengths of piles found necessary under different portions of the dry dock, we would expect that, if any settlement had actually occurred, it would not be uniform over all parts of this very large structure. To test this, levels were taken all around the bottom of the dock and along each step of the altar, by Henry B. Wood, C.E., on April 17, 1903.

The entire bottom of the dock was found remarkably true to line and level, hardly more than ⅛ inch deviation from a level line being found in the level of these steps for the entire length of the dock. The bottom was also at almost the precise distance below the various steps of the altar called for by the plans; a slight crown or bulge was apparent near the middle of the floor, which, it is possible, may have been produced by the strains due to buoyancy, although that this was wholly so produced is doubtful, in view of the wedge-shaped form of the stones forming this thick floor revealed by the original drawings, and the fact that the new dock is being built with a crowning floor. The steps of the altars are but the points of deep voussoirs which help spread the weight of the side walls and resist buoyancy. It is possible this crowning was designed to aid in drainage and in giving a dry floor to work on.

An inspection of the joints between the stones of the floor and those in the lowest steps of the altar shows them in good condition, and the distortion and lifting by frost have occurred chiefly under the edge of the midway broad altar and in the horizontal joints of the vertical side walls above these steps.

Good and sufficient proof that the bottom of the dock has not settled is found in various lines of bench levels run from the dock to sundry points in Boston and Charlestown during the past fifty years. These agree remarkably well, and the discrepancy between them can all be accounted for by the proved swelling of the joints which has lifted the coping.

Boston Datum Planes.

Before reviewing these various lines of bench levels, we will briefly review the history of the principal standard datum planes used by engineers in determining and recording elevations about Boston.

Tide marsh level, or mean high water, was the datum used on the water works from 1850 to 1895.

In the general city work a datum 10 feet lower was used, in order to avoid negative heights in sewer work, etc., and *this datum was called mean low water*, and supposed to be mean low water until 1878, after which an incomplete study resulted in calling it 0.64 below mean low water.

This is the datum plane now in almost universal use on public and private work about Boston (except in Cambridge, which uses a datum about 5 feet higher).

Datum Planes for Earliest Surveys, "Tide Marsh Level."

"Marsh," "tide marsh," "marsh level" or "tide marsh level" is the earliest datum plane of which I have found mention. I have not yet found a positive record of how marsh level was determined, or for just what purpose it was originally established, or by what benches it was originally defined, or who established it, but there is excellent proof that *it was the same, or very nearly the same, as mean high water of* 1830.

In one of the very earliest note books of the Boston city engineer's office, notes of Thomas Williams and Charles Perkins, 1849–50, is the statement: "*The coping of the dry dock is* 5 *feet above 'marsh level;'*" and in connection with B. F. Perham's statement on the harbor survey map of 1836, this shows that "tide marsh" or "marsh level" used as a datum plane was the same as mean high water.

The first surveys for the introduction of a public water supply to Boston were made under the supervision of Loammi Baldwin,* by B. F. Perham, the engineer whose name appears as draughtsman of several of the earliest plans of the dry dock, and the lithographed map presented in Baldwin's report is dated Sept. 30, 1834. This antedates the Baldwin-Perham harbor survey by a year or more, and its profiles all refer to "marsh" or "tide marsh" as the datum plane, in a familiar way that implies this to have been the recognized datum plane of those times, but in some parts of this report there are statements which imply that some of the levels for approximate purposes were run to the nearest tide marsh. Mr. Baldwin in 1834 was fifty-four years old, and had long been charged with the most important engineering work in New England, and possibly this "marsh level" was the datum plane of some of his previous work; or it may have been established in connection with the building of the dock.

The earliest reference that I have found to "marsh level" as a datum plane is in the writings of Loammi Baldwin, and I think it not improbable that, as a datum plane for engineering levels, it was established by him from tidal observations somewhere between 1825 and 1830, but I have no proof of this.

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* This 1834 report on a water supply for Boston is a very remarkable report on public water supply, when the date is considered. Its depth and profundity of knowledge and its quality of careful analysis all breathe of Loammi Baldwin's genius, and indicate that such a man would not build a dry dock with its coping out of level or at a loosely fixed height above mean high water, or be careless about his datum plane.

Its use for surveys in connection with the Boston water supply was continued until the works were taken over by the Metropolitan Water Board in 1895.

I have examined copies of the canal and railroad reports of 1826 and 1829 on file in the State Library, in the hope of finding some more definite description of the "tide marsh level" datum plane.

On p. 112 of the canal report of 1826 it is stated: "The heights of the following points, as ascertained in the surveys and cross-levels for a canal from Boston to the Connecticut River, are counted from low-water mark in Boston harbor. The level at low tide is taken at 10 feet below the marsh at the foot of the old dike on the east side near the Boston cordage factory." Full basin of the Boston and Roxbury Mill Corporation 10.80 feet by this scale, surface of pond water above the dam at Watertown 14.48 feet. Bemis mill pond 20.44 feet, and thence continues a table of heights of prominent points crossing the State.

In James F. Baldwin's report of 1829 on railroad from Boston to Hudson River (Loammi had turned this work over to his brother, because of his own appointment to build the dry docks), on p. 65, etc., is given a table of elevations, all referred to "height above the marsh," but I do not find this defined by a definite location on a permanent bench mark or by tidal observations.

Tidal observations for the determination of mean high water had been made before that time, for in 1824, in Daniel Treadwell's report on the introduction of water, p. 10, we find this: —

"It appears from a survey by Mr. Fuller that the surface of this [Spot] pond taken 2 feet below the wasteway is 140 feet above the *level of high water at mean tides;*" and on p. 16: "Now the water above the falls at Watertown is about 4½ feet *above the mean tides in Boston.*" (Compare with the 14.48 feet given for the elevation of this pond above low-water mark in Boston harbor given by previous note from Baldwin's Hudson Canal survey of 1826.)

In 1834, Loammi Baldwin, on p. 40 of his report on introducing pure water, says: "Area of Spot Pond is 260 acres, and it is 143.58 feet above the marsh in Medford." This makes his pond level 1.58 feet above the wasteway noted by Fuller.

The addition of the words "in Medford" may imply that for a short cut he simply levelled down to or up from the average level of the marsh at its nearest point to Spot Pond, and so saved 5 miles of levelling.

In 1845, in report of commissioners to examine the sources of pure water for Boston, p. 83: "Water in Corey's Hill reservoir may be taken at a constant elevation of 121½ feet above marsh level, or ordinary high tide." The terms *ordinary high tide* and *mean high water* appear to have been regarded as synonymous.

On a profile and plan of the proposed aqueduct, in city engineer's office, dated 1848, it is stated that the datum of this profile is 9.64 feet below "*tide marsh level.*"

In 1844, on plan of East Boston, by P. H. Eddy (a former student of Baldwin), showing the lots, the line of low water is marked "*Low-water mark* 15 *feet below coping of Charlestown dry dock.*"

Notwithstanding the fact that under Loammi Baldwin, in 1834, B. F. Perham used "marsh level" as the datum for his levels to Lake Cochituate (then called Long Pond) for the earliest report and survey on a water supply from this source, and that L. B. Russell, surveying for the Water Supply Commission in 1837 on a profile from Lake Cochituate to Boston, used "marsh level" for his datum plane, and that this Russell profile was duplicated in the report of the commissioners of

1844 immediately prior to the beginning of construction, it appeared, according to an investigation into the history of the old bench marks for the Metropolitan Water Board when they began work in 1895, made by W. E. Foss, division engineer, that the first bench levels surveyed immediately prior to the construction began *at the lake with a random bench* or an assumed height, and ran toward Boston or to the site of the reservoir in Brookline now known as the "old reservoir." As this line in running down hill soon found negative values, the datum plane was dropped 200 feet in 1849 when continuing this line of levels into Boston. One of the most notable bench marks established in Boston by these levels at that time was on the standard of the scraper at the doorway of 59 Hancock Street. This was found to be at 164.555 by this base, which we will call the "Slade-Cochituate base."

In 1849 Thomas S. Williams surveyed and levelled for a pipe line from Beacon Hill, Boston (and from the bench at 59 Hancock Street above mentioned), to East Boston by way of Charlestown and Chelsea; and, since he thus had to run close by the Navy Yard, a spur line was run into check on the dry dock coping; this was with single readings, and not checked back until some months later, when Charles Perkins re-ran it, and made it .035 foot different.

At the bottom of his first page of notes is the statement that this water works datum (*the Slade-Cochituate base*) *is* 79.640 *feet below "marsh level*," which figure I take to have been a prior determination from a comparison with the marsh heights on benches in Boston; and this page of the note book contains a statement that "*the coping of the dry dock is* 5 *feet above marsh level*."

As Williams levelled along he appears to have found that the coping of the dry dock was 84.729 by the Slade-Cochituate datum, with which he had started; and that, as a check, subtracting the 79.640 by which "marsh level" was supposed to be above the Cochituate datum, he found 84.729 minus 79.640 equals 5.089, for the distance of the coping above tide marsh.

His note book, in fact, contains the words "Level by Mr. Haile from nail" (at corner of curbstone corner of Hawley Place and Chestnut Street, Charlestown) "makes the coping of the dry dock 84.729 above marsh by our levels;" and *it is apparently by subtracting this* 5.09 *from the* 15 *feet at which Boston base was supposed to be established below the coping that the difference of* 9.91 *was derived, which was so long used for the relation between Boston base and tide marsh level*, — a curious instance of a single hasty or chance determination posing as the authoritative value for half a century.

This was not the first use of marsh level as a datum on the newly constructed water works; for a few months prior to this, or on Jan. 1, 1849, it is stated by Mr. Foss that a note book states that the bench mark on the floor of the effluent gate house is at 126.76 by marsh level; but how that was determined does not now appear; and it now appears probable that some other levels than those of March 13, 1849, furnished the original tie between the Slade-Cochituate base and marsh level.

It is probable, although I have not yet found the full proof, that a new city datum 15 feet below the coping of the dry dock was first proposed and established about 1850, and that, *according to the belief of those who built the dry dock and the intention of those who were establishing this new base, this new datum plane or Boston base was established exactly at the mean low water of* 1830.

A side note in Perkins' note book of 1850 says: "84.729 — 15.000 equals 69.729 difference of base" (Slade-Cochituate, below city).

In Wm. Gossip's note book No. 18, city surveyor's department, we find, under list of benches within .01, "Standard of scraper No. 59 Hancock Street, 94.915 city base."

	Feet.
Since by the "Slade-Cochituate" base this was	164.555
If the Slade datum was below marsh level	79.640
We get for the height by the marsh level datum	84.915
While the note just quoted gives it by city base at	94.915
Indicating an understanding that the distance of the proposed new Boston base below tide marsh level was	10.000

There is good reason to believe that *Boston base was intended to be exactly* 10 *feet below the old marsh level datum, and that the value* 9.91 *came from the single spur line of levels by Williams in March*, 1849.

Another spur line off the Williams Charlestown-East Boston line was run to the dry dock coping in 1850 by Mr. Charles Perkins, which made its top at 5.054 above the tide marsh datum defined by the benches started from, instead of 5.089, and this would have made the difference 9.95, instead of 9.91.

I am told by Mr. F. P. Stearns and Mr. Dexter Brackett, of the metropolitan water engineers, that an extended re-running of the old Cochituate bench levels from Beacon Hill back to Chestnut Hill and thence back to the lake was made some years ago, which showed that the difference between the old marsh level values and the Boston base values averaged just about 10 feet, and that this is the value that has since always been adopted in their office. They also state that the new and very careful levels showed the old lines to have been run with a good degree of precision.

In considering the values of 5.089 and 5.054 for elevation of top of coping of dry dock above marsh level, which Mr. Williams (from the note at the beginning of his book) had evidently expected to find at 5, we must remember that in 1850 the wall probably had been rising under the influence of frost for about seventeen to nineteen years, and that the point levelled upon may have been either at the head of the dock where Harris took his bench mark in 1854, or may have been at the Coast Survey's old bench mark at the outer corner. The coping at the head of the dock had at that time probably not lifted more than .02 foot, and at the outer end had not then lifted more than 0.11 foot, if proportional to time as by diagram on p. 555, and a lifting up to .054 foot or .089 foot would account for the difference found by Haile and Perkins noted at the beginning of this paragraph.

In Williams' note book No. 1, p. 132, is a computation in which the following notes appear: —

> 84.729 is coping of dry dock (Slade-Cochituate base).
> 15.000 is mean low water below coping.
>
> 69.729 is base of water levels (Slade-Cochituate) below mean low water.

In going over the old note books a very few memoranda are found which give contradictory evidence; for example, in this Williams note book of 1851 is a note that gives mean low water as 14.7 feet below the coping, whereas 15 is the value more often found; 14.7 is the value stated on the harbor survey map of 1847 from a series of tide observations that appears to have been brief and not very precise.

In a report by Wm. Parrott, Oct. 31, 1849, on grades in East Boston, it is stated, p. 237 of record book: "*The base line for vertical distances is the same as that used in Boston proper*, and was transferred across

the harbor in order to have the same standard of comparison and also for a base to be used in arranging the sewerage." On p. 243 of record book: "The plane of reference is taken at the height of the coping of the dry dock at Charlestown, and the base line of the profiles 15 feet below that plane, which is assumed to be the plane of *low water spring tides*." These last four words are plainly in error.

In 1837, in a report on the proposed public water supply, made by Commissioners Daniel Treadwell, James F. Baldwin (the brother of Loammi) and Nathan Hale, is presented a map of a survey made by L. B. Russell, on which "marsh level" is used for the datum of the profiles; and it is there stated that this base is "4.07 feet below the coping of dry dock in Charlestown." But this was plainly 1 foot in error.

Boston Base.

It was natural that the marsh level datum should be abandoned about 1850, when sewer construction became more active, following the introduction of water.

It is plain that the marsh level datum, while all right for water works, would become very inconvenient and give negative values in sewer construction; and, as already stated, mean low water appears to have been selected.

A very careful series of bench levels was run by C. H. Harris, in 1854, to more thoroughly establish this new Boston base, and his bench heights have been the general standard for nearly fifty years.

He started from the top of the coping of the dry dock near its in-shore end (not near the outer end, where the Coast Survey bench was located) (see note book 22, city surveyor's office), "from the west end of the dock, right side of centre on curved stone on which is an inscription," and called the height of the coping at this point 15 above the new "Boston base" datum. Passing over nine turning points, he recorded the bench mark at No. 162 Prince Street in Old Boston (long a standard, but recently found disturbed .08 foot), and repeated the levels to this point back and forth five times, and part way for the sixth time, and finally adopted the average value of 21.326 for this Prince Street bench. The greatest variations from the mean by any one of the six runs was .027 foot, and the average variation .010 foot.

Thence he ran a circuit around through Commercial, Broad, Harrison Avenue, Dover, Tremont and Charles streets, checking on old benches quoted as probably correct "within .01" foot, and finding small differences both plus and minus, some as great as 0.13 foot. On an old standard bench, on the underpinning of a house on Tremont Street, opposite Dover, about the farthest point from Navy Yard reached on this circuit, Harris' height was .033 lower than the old height; and on p. 132 Harris makes a comparison with the old water levels on the "Slade-Cochituate base" on this bench: —

	Feet.
Slade-Cochituate height, ...	79.896
Difference in bases, 84.729 — 15.000 equals	69.729
Bench mark opposite Dover Street above mean low water, ...	10.167

This again plainly indicates that Harris supposed he was establishing bench levels by a datum that was at *mean low water*.

	Feet.
The elevation of this bench given in book 18, p. 5, was	10.156
Harris, by his own levels from Navy Yard, made it	10.123
Difference, ...	.033

At No. 36 Greene Street, Harris made a bench mark at	33.570*
Harris continued to a bench at No. 68 Beacon Street, which he made . . .	20.143*
And later continued his levels to the old bench on the floor of the effluent gate house at the old Brookline reservoir, which he made	136.714*
And checked back to Beacon Street again within .003 foot (see survey book 22, p. 68).	
This bench by the old tide marsh levels (1849) was called	12.676
And this comparison makes distance of "tide marsh" above Boston base .	9.950
Or as nearly 10 feet as could reasonably be expected.	
Harris from his bench at 36 Greene Street levelled (book 22, p. 62) to the old bench on the standard of the scraper at 59 Hancock Street, Beacon Hill, making this	94.919*
This bench by the Slade-Cochituate base was	164.444
So the Harris comparison makes the difference between Boston base and the Slade-Cochituate base, ...	69.636
The former value for difference between Slade and marsh level, — how obtained is not now clear, — mentioned by Williams in 1849, was	79.640
This makes the difference between tide marsh and Boston base, ...	10.004

The coping stone started from by Harris in 1854 was moved when the entire end masonry of the dock was taken down, while the dock was lengthened 65 feet above 1858, all stones being carefully numbered and relaid in their former relative positions; but it is probable that it was reset very nearly at its former height, and that it was reset level with the rest of the coping in its vicinity.

This particular stone is now at the general level of the wall, and, since all parts of the wall coping inside the old turning gates have now been lifted to nearly the same extent (about 0.12 foot), this had probably lifted about 0.02 or 0.03 in 1854.

I consider that the review of these old notes makes it almost absolutely certain that: —

1. Tide marsh level was the same as mean high water of 1830.
2. Boston base was established 10 feet below tide marsh.
3. Boston base was supposed to be established at mean low water.

But, since mean low water was defined by the coping which had its relation to the tides determined about 1830, these tide levels were those of 1830, and not the tide levels of 1854.

Further Proof that Dry Dock has not settled.

Sundry lines of levels from the dry dock to various bench marks in old Boston, made at various times during the past fifty years, prove that there has been no appreciable change in their relative elevation; and from sundry memoranda on plans and in old note books there is excellent reason to believe that levels run from the dry dock to Boston and over through Boston nearly sixty years ago agree with the recent levels. The most noteworthy old comparisons between the dock and bench marks on solid ground in old Boston and out along the old aqueduct, of which we have yet found record, are the following: —

January, 1849: A note is found under date of January 1 which, by giving the elevation of a bench on the floor of the effluent gate house of the old Brookline reservoir of the Boston water works in terms of "marsh level," indicates that lines of levels between the dry dock and the water works had been run prior to 1849.

March, 1849: Thomas Williams ran a line of levels from an old standard bench at 59 Hancock Street, on standard of a door step scraper, over to East Boston, by way of Charlestown, and, in passing, ran a spur line into the Navy Yard for a check on the dry dock coping.

* Boston base.

1854: The most careful and painstaking series of old levels of which we find a record are those by Charles Harris, that were run in order to establish a general series of standard benches throughout Boston. He started from the head of the dry dock, from the top of the curved coping stone nearest the centre, which without doubt had substantially the same general elevation as all of the coping near the head. This stone was moved about 1858, when the dock was lengthened. He repeated his line of levels from the dry dock to his bench mark on Prince Street five times, and in part six times, with good agreement; and, calling the coping 15.000, found the elevation of his Prince Street bench mark 21.326 above "Boston base." The greatest difference from the mean found in any one of these six repetitions was .027 foot, and the mean variation .01 foot. He also left numerous other bench marks in old Boston.

In 1867, George R. Baldwin, having set his tide gauge at India wharf by levels from two or three old benches, so as to determine its height above Boston base, checked this height by simultaneous observations of the water level at slack water of high tide at India wharf and at the Navy Yard; and he found, starting with Boston base, as defined by the old benches, that the elevation of the coping at or near the turning gate was 15.15 by Boston base; but this method of water levelling, while excellent for an independent check, is less precise than a careful line of instrumental levels.

In 1874, C. A. Metcalf levelled over to Charlestown from the Harris benches, in order to establish benches for future use in this district which had just been annexed to Boston. Taking for his datum Boston base as defined by the Harris benches, he found the dry dock coping at 15.10, or about 0.10 foot higher than twenty years before. This plainly shows that no settlement of the dock had occurred; and, of the increase of 0.10 foot, about .03 may be accounted for by the swelling of joints in this twenty years from 1854 to 1874, and a part of the remaining .07 foot by lack of precision and a part by having to measure to a different portion of the coping, because the original starting point of Harris had been moved.

In 1878, a very careful series of levels was run by F. M. Miner, of the city surveyor's office, Boston; and throughout many districts his heights agree remarkably well with those found by Harris twenty-four years before. Starting with elevations shown by the Harris levels of 1854 from bench marks at and near Prince Street, he finds the height of coping at the "new bench mark" 15.13 by Boston base (or .03 higher than Metcalf four years before), instead of the original 15.00; which shows a lifting and not a settlement of the dock during these twenty-four years. By the diagram on p. 555, 0.04 foot of this rise can be accounted for by the swelling of joints in the masonry, and the remaining 0.09 foot by the fact that a different point on the coping was used for a bench, and by lack of precision of measurement.

In 1903, twenty-five years later, Mr. Miner had a part of this line again re-run. Starting from some of his other old benches near Prince Street (because of the Prince Street bench being found apparently disturbed 0.08 foot), he found the elevation of new bench mark at 15.12 by Boston base. The Miner levels of 1878 and the Miner levels of 1903 both touched on the coping at the "new bench" on the dry dock coping over the arrow, established by the Coast Survey in 1867, and the same point which is now found to be 30.12 feet above the average level of the dock sills.

Obviously this datum plane of Boston base, which has been the standard of the city engineer's office for more than fifty years, and which (with the 10 feet deduction for "tide marsh datum" and the 100 feet addition for the metropolitan sewer datum) has been used in the widely extended work of water supply and sewer construction for many miles inland and along the coast, is rigidly defined by hundreds of ties to ledges and to ground solid as the foundations of the hills; and, taken as a whole, this datum plane furnishes the best standard for testing any movement of the dry dock.

The ancient levels between permanent bench marks agree excellently with the modern levels everywhere except over the made land of the Back Bay and a few other pieces of soft ground, and *the dry dock holds substantially the same relation in height to these many benches, and by*

all of these independent determinations, that it did fifty or sixty and seventy years ago.

Probably an exhaustive study would disclose sundry other comparisons between the dry dock coping and benches on solid ground. The series of note books of Thomas Doane (now largely in possession of the Boston & Maine Railroad) would doubtless give many ties from the dry dock to points in Charlestown, and probably a history of the Cambridge bench marks would add to the evidence; but the comparisons given above present ample proof that the fact that tides rise about seven-tenths of a foot higher on the walls of the dock than they did about seventy-two years ago *cannot in any degree be attributed to the dock having settled into the surrounding earth.*

Tide Gauge Comparisons.

(1) We have in the preceding pages demonstrated that the sills and bottom of the dock have not settled appreciably in fifty years relative to the elevation of the solid ground.

(2) We have demonstrated that certain points on the coping have been lifted by the frost at a rate which we have determined approximately, and shown in a diagram on p. 555.

(3) We have also found that the bronze tide gauges inlaid in the faces of the dock walls have been lifted and stretched in their upper portion by the action of ice, frost, etc., and we know the present correction to the elevation of these marks (p. 553), and can approximate roughly to the rate at which they have been lifted from year to year.

(4) We have proved, by statements found written on the original construction plans of the dock, that its coping was set (in 1831) at 5 feet above mean high water, and found this confirmed by notes on the plan of the harbor, made by the precise surveyor and draughtsman Perham, soon after the dock was built; and have found it a matter of common report among the contemporary surveyors and engineers that the dock was built with its coping at precisely 5 feet above mean high water and at precisely 15 feet above mean low water, as is shown by memoranda written in the oldest survey note books now found in the archives of the Boston city engineer, thus making this coping at 10 feet above mean sea level; and by all contemporary surveyors and engineers of prominence, so far as known, the coping of this dock was accepted as the best and most permanent bench mark in the vicinity of Boston for defining elevations with reference to the level of the sea.

Tide Gauges of 1847.

(5) The next series of tidal records is the brief and incomplete one consisting of observations made during the soundings for the harbor survey map of 1847.

This survey was executed by the United States Coast Survey for the commissioners, Thomas G. Carey, Simeon Borden and Ezra Lincoln, under a resolve of the Massachusetts Legislature passed April 16, 1846. A brief statement of the objects of this survey is found in Senate Document No. 25 of 1847, — "To examine the position of the flats in the harbor of Boston between South Boston and the channel," etc.

This appears to have been the original study for the improvement of the South Boston flats, executed thirty years later. This report states that the work of the coast survey was not begun until August, 1846. The lines of soundings are very few and far between, compared with the Perham, Boschke or Low maps, and it was plainly a reconnaissance.

Our chief reason for considering it here is that the published map contained a statement regarding tidal heights, which appears to have been in the view of certain of the city surveyors two years later, when they were running levels to establish standard bench marks for Boston base, but which tidal heights were not determined by a long enough series of observations to be of much value.

Certain dates and reference notes on the map indicate that the surveying was done almost wholly in the four weeks, Oct. 30 to Nov. 26, 1846. Presumably the tide gauges covered only the same period. It was in charge of Lieut. C. H. Davis, the same who started the long series of tidal observations that were begun the following June, and who adopted the top of the coping over the south-west bronze scale for his standard base.

The figures given on the plan show that he measured his heights from the same datum as these dry dock tide staffs. Whether he relied upon the bronze foot marks solely for these observations is not known, or whether a temporary staff with closer divisions; or whether, if so, the measurement was from top of coping, and thus introduced whatever error had come from the lifting of the coping by frost up to that time, which, if uniformly progressive (as per diagram on p. 555), had then amounted to only about .05 foot. He states that his elevations are referred to the coping of the dry dock as a permanent plane of reference. He finds mean low water 14.7 feet below the coping; mean high water 4.3 feet below the coping; mean sea level 9.5 feet below the coping; mean range of tides 10.4 feet.

This mean range being so much greater (4 to 6 inches) than that since found, casts some discredit on the precision of this determination, and leads one to suspect the influence of abnormal winds, or gaps in the series of observations required for a complete lunation. I have therefore not plotted it on the diagram of tide heights at different points.

Coast Survey Series of Tide Gauges.

(6) The next series of tidal comparisons available are those of the United States Coast Survey, which maintained here in the vicinity of the dry dock one of its longest and most important series of tidal observations, continuing from 1847 to 1876, — twenty-nine years. Unfortunately, the changing elevation of the dry dock coping was not well understood by those in charge, and the records showing just what the tide staff was on which their observations were made, or just how it was compared and corrected for elevation by bench levels, are very incomplete.

A statement furnished Mr. Van Orden in 1893 from the Coast Survey office, relative to the height of sea level, and which I find has been copied and used as authority in the offices of the city engineer of Boston, the Metropolitan Water Board, the Harbor Commission and the Bureau of Yards and Docks at Charlestown Navy Yard, says that for about twenty years from 1847 the observations on high and low water "were read from a fixed staff made by inserting pieces of copper into the face of the granite sea wall on the south side of the entrance to the dry dock at the Charlestown Navy Yard," etc.;* but other

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*Office of the Coast and Geodetic Survey,
Washington, May 7, 1903.

Mr. John R. Freeman, Providence, Rhode Island.

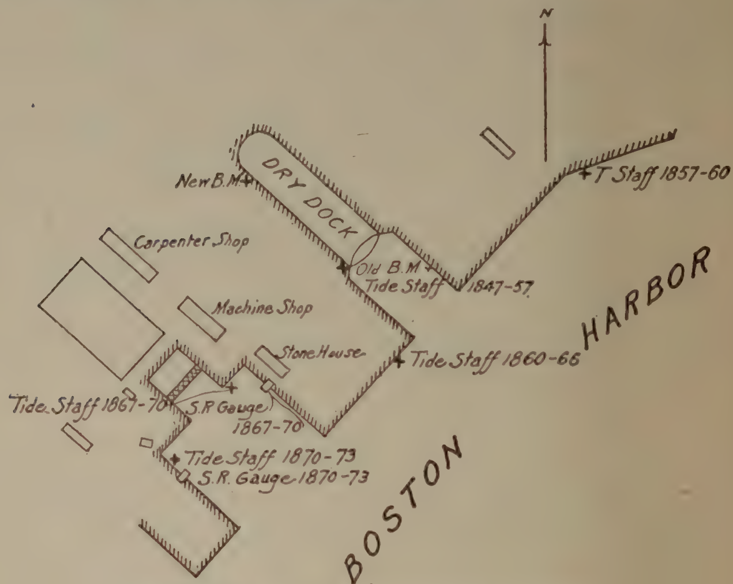
Sir: — In reply to your letter of the 27th ultimo, I have to state that an examination of the original record of tidal observations at Boston Navy Yard, Massachusetts, between 1847 and 1860, does not furnish any very satisfactory statements in regard to the method of making the observations. There are but very few notes, and most of them merely state that a portable tide staff was used to read the decimal parts of the feet indicated by the copper scale set in the sea wall. Nothing is said as to how this movable rod was supported, but it seems possible, to say the least, that it may have been provided with a shoulder to rest upon the coping of the wall. We find a statement that the copper scale was used from 1847 to 1860, and that about then a box gauge was put up, which read the same as the copper scale, the series being continued on this gauge until 1867, when an automatic gauge was used.

There are a number of old letters on file here which state that the sea wall of the dry dock was repaired at times; but the original tide records do not mention the fact, and we do not know how the tides were read while the stones bearing the copper scale were temporarily removed.

Respectfully yours,

O. H. Tittmann,
Superintendent.

information indicates that in 1857 the tide staff was shifted to a point about 400 feet easterly, kept there for three years, until 1860, then shifted to a point 200 feet south-westerly from the face of the dock, kept there from 1860 to 1866, and then, Aug. 16, 1867, a self-recording gauge was established at a point 150 feet south-westerly. It was in 1867 that "new bench" was selected. All of these locations are shown in the following sketch.



CHARLESTOWN NAVY YARD TIDE GAUGE LOCATIONS.

Unfortunately, this copper marked staff had stretched, and was inaccurate, and it is uncertain whether the portable staff graduated to 0.10 foot used in taking the height was used to interpolate between the copper foot marks, or was used to measure down the whole distance from the top of the coping.

Between the dislocated bench mark, the expanding, copper marked tide staff, the frequent shifting of the location of the gauge and the scanty records of how gauges were set and observed, it is impossible to extract information that is sure and precise.

The fact that the officer in charge is reported to have begun by establishing a permanent bench mark on the coping directly over the gauge, "to which the observations have been referred,"* would seem a needless formality, unless this was to be used as the reference mark in setting a new, more legible and more finely divided wooden staff; but, on the other hand, there were doubtless facilities handy for the observer to get down close to the tide staff on a float, and apply a short measuring stick for the subdivisions.

"The observations were begun June 1, 1847, under direction of Lieut. C. H. Davis, commanding the schooner 'Gallatin,' and continued seemingly without interruption for ten years" to 1857.

* This only means that he called the smooth top of this coping stone "elevation 30," because of it being found exactly 1 foot above the 29 mark on the inlaid "copper" or bronze scale. No "monument cut" was made to mark the spot.

July 9, 1857, the observer reports "the wall of the dock has settled 4 or 5 inches" (or 0.37 foot).

The observer was plainly wrong, unless he was referring to some observations that showed the sill of dock was then about 25.37 feet below mean high water, whereas originally it was 25 feet.

The Bureau of Yards and Docks occasionally prepares statements for use in docking ships showing approximate depth over the sill; and, for example, the blue-print giving this data for the year 1900 shows a depth of 25.56 feet.

I have plotted the yearly means of these tidal observations, as furnished me from the Coast Survey Office, which are the same as given in Table No. 7, report of United States Coast Survey, 1868, p. 80, on the following diagram.

All from 1848 to 1866 are plotted just as the record is given; but, since the observations subsequent to 1867 are reckoned from a different datum, and it is stated explicitly that in setting up the porcelain tide staff in 1867 *its* 20 *mark was placed "level with the old bench mark* (then called 30), at which time, after the repairs, the old bench mark was 0.155 foot above the new mark," and again in 1870, when tide gauges were removed to another wharf, "*the* 20 *foot mark on the porcelain staff was set level with the old bench mark*, and a new levelling gives the old bench mark 0.153 foot above new bench mark;" and since my own deductions (see diagram of change in bench marks on p. 555) make it appear probable that the old bench mark had at that time become lifted 0.21 foot by frost above its original height, — I have added 10.21 to the reported heights when plotting them, *thus bringing these records by the recording gauge from* 1867 *to* 1876 *to the original dock-sill datum.*

These tide gauge records from 1867 to 1876 are the only ones in the Coast Survey series about whose exact relation to the dock-sill datum, or to Boston base, we are at all certain.

The series from 1848 to 1857 inclusive is, however, surely not much in error. If, as is stated, they were actually observed upon the inlaid copper, or bronze, foot marks, probably using the portable scale to obtain the fraction between the foot marks, then, since the coping of the wall had in 1853 probably become lifted only about 0.12 foot (per diagram on p. 555), and since we note by table on p. 553 that the 16 mark is now in 1903 lifted only about one-quarter part as much as the top, it is probable that the mark near low water had lifted only about .03 foot in 1853.

At high water the 25 mark had then, as now, probably not lifted more than about three-quarters as much as the coping, or, say, 0.09 foot. Averaging these, we find it probable that the mean sea level, if accurately referred to the true dock-sill datum, should be raised 0.06 foot on the plotting.

On the other hand, if a long, correctly graduated portable staff had its 30 mark set level with the bench, then the plotted height should be lifted 0.12 foot. The .06 foot is, I think, the more probable value.

The three years' observations, 1858–60, with gauge at pier 400 feet easterly, on the supposition that bench 30 was 0.15 too high, and that the 30 mark of gauge was set level with the coping, should have 0.15 foot added to the plotted height. The possibility that the correction originally applied in reducing the observations may have in some way reflected the notion of the observer that the dock had settled 4 or 5 inches, is exceedingly remote.

For the six years, 1861–66, the new box gauge, set 100 feet southwesterly of dock, was beyond a doubt graduated properly, and natu-

rally would have been so set that its 30 mark would be level with the top of the coping, which at that period was at about 30.20 above the dock-sill datum. Therefore, 0.20 should be added to the height, as stated in the record.

When the new self-registering gauge was set, in August, 1867, Captain Mitchell also made note of the excess in elevation of the old bench mark over other portions of the wall, and established the "new bench mark" near the head of the dock, and stated, "The old bench mark does not exist, the dry dock having been rebuilt;" which, being interpreted, probably means that one or more stones under the old bench had been loosened by frost and reset within a floating "coffer-dam,"* and that the coping stone used for a bench, and perhaps one course below it, had been relaid.

A year later, June 17, 1868, a letter on file at the Coast Survey office says: "The old bench mark is 0.176 foot higher than the new."

It now looks as though the three facts, (1) that many of the joints between the heavy stones were opening, (2) that the inshore portions

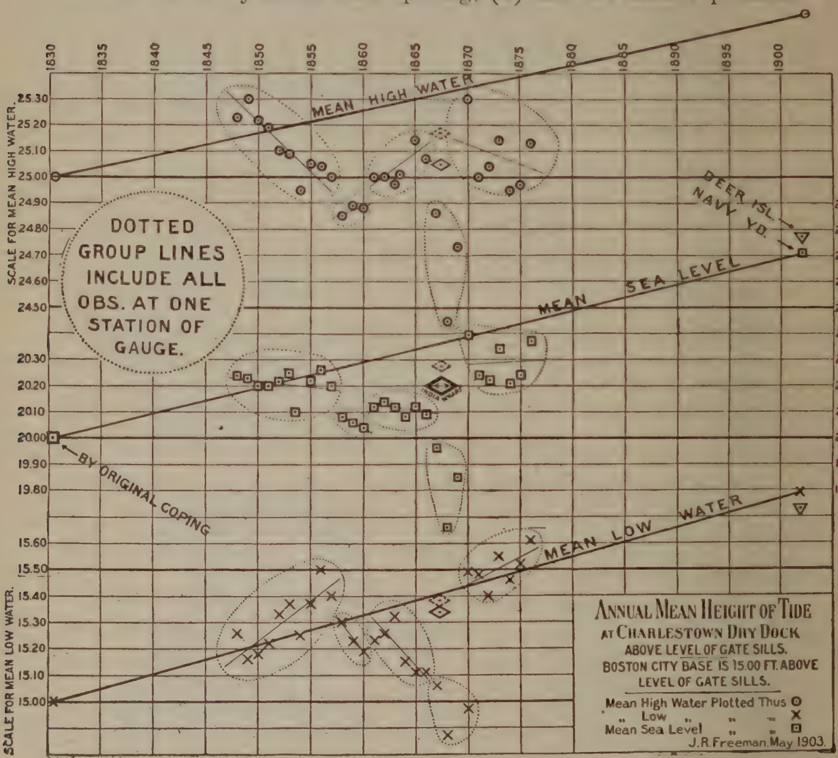


DIAGRAM SHOWING MEAN HEIGHT OF TIDE EACH YEAR, 1830 TO 1902.

of the wall were manifestly lower than the outer portions, and (3) that the depth of the sills and of the lock as a whole was found lower rel-

* Of which construction plans are on file in the engineer's office at the yard.

atively to high and low water than was stated on the old plans, *were wrongly interpreted as proving that the dock was slowly settling*, and more at some parts than at others; but, very curiously, no effort appears to have been made to tie its level on to any of the many bench marks on the solid ground in Charlestown or Boston established by Thomas Doane, the Baldwin brothers or other engineers.

The gauge datum used in the Coast Survey work from 1867 to 1873 is plainly wrong, as is shown by these heights falling so abruptly out of line on the diagram, and proved by the careful series of tidal observations by the State engineer at India wharf in 1867–68, who established his gauge datum at Boston base by levels to two of the standard benches of Harris, and prudently checked it by water level to the coping near one of the inner bronze gauges.

The above diagram brings out clearly the probable rate of change from the time the dock was built until the past year.

Probably for showing the rate of change the two best pieces of data on this diagram are the first and the last. While, unfortunately, we have not found the full record of the original determination of mean tide about 1830, there is good reason to believe that it was carefully and accurately done.

Boston Harbor.—India Wharf Tide Record, 1867–68.

Table of Means of High and Low Water during Lunations from September, 1867, to June, 1868, from Recording Gauge maintained by Geo. R. Baldwin, State Engineer, Massachusetts. Transcribed and computed February, 1903, by W. E. Spear, C.E., and G. W. Armstrong, C.E., for John R. Freeman, C.E., from the Original Autographic Charts on File in Office of Chief Engineer of Massachusetts Harbor Commission.

Lunation. From—	Lunation. To—	Average Elevation of High Water above Boston Base (of 1878).	Average Elevation of Low Water above Boston Base.	Range of Tide.	Mean Sea Level above Boston Base.
1867.	**1867.**				
Sept. 13, 7 A.M.,	Oct. 12, 8 P.M.,	10.290	0.60	9.690	5.45
Oct. 12, 8 P.M.,	Nov. 11, 8 A.M.,	10.145	0.64	9.505	5.39
Nov. 11, 8 A.M.,	Dec. 10, 7 P.M.,	9.985	0.35	9.635	5.17
	1868.				
Dec. 10, 7 P.M.,	Jan. 9, 6 A.M.,	10.130	0.69	9.440	5.41
1868.					
Jan. 9, 6 A.M.,	Feb. 7, 4 P.M.,	9.880	0.02	9.860	4.95
Feb. 7, 4 P.M.,	March 8, 3 A.M.,	9.380	0.04	9.340	4.76
March 8, 3 A.M.,	April 6, 2 P.M.,	10.170	0.06	10.110	5.12
April 6, 2 P.M.,	May 6, 1 A.M.,	9.870	0.03	9.840	4.95
May 6, 1 A.M.,	June 4, 2 P.M.,	10.580	0.63	9.950	5.60
Sums, ...		90.430	3.06	87.370	46.80
Mean, ...		10.050	0.34	9.710	5.20

Geo. R. Baldwin assumed his base for this recording gauge at 5 feet below Boston base. His levels were made from three bench marks, the heights of which were determined by Harris's levels. The heights of these bench marks would have been 0.02 foot greater by Miner's bench levels and datum of 1878, so that the correction to Baldwin's datum is 4.98 feet, and this has been used in obtaining the above.

Charlestown Navy Yard. — Tide Observations during 1902–1903. Computations of Mean High and Mean Low Water. Summary of Results (computed from Autographic Charts by W. E. Spear and G. W. Armstrong for John R. Freeman, March, 1903).

Lunation (beginning with New Moon). From—	To—	Mean of Heights of Low Water above Mean Low Water, Navy Yard Base, which is 14.54 Feet below "New Bench Mark."	Mean of Heights of High Water above Mean Low Water, Navy Yard Base.	Mean Sea Level during Lunation above Mean Low Water, Navy Yard Base.	Mean Range of Tide during Lunation.
1902.	1902.	Feet.	Feet.	Feet.	Feet.
Feb. 8, 8 A.M.,	March 9, 10 P.M.,	+0.175	10.104	5.140	9.929
March 9, 10 P.M.,	April 8, 9 A.M.,	+0.274	10.173	5.224	9.899
April 8, 9 A.M.,	May 7, 6 P.M.,	+0.338	10.040	5.189	9.702
May 7, 6 P.M.,	June 6, 1 A.M.,	−0.062	9.906	4.922	9.968
June 6, 1 A.M.,	July 5, 8 A.M.,	+0.047	10.130	5.089	10.083
July 5, 8 A.M.,	Aug. 3, 3 P.M.,	+0.059	10.101	5.080	10.042
Aug. 3, 3 P.M.,	Sept. 2, 12 Mdt.,	+0.278*	10.009*	5.144*	9.731*
Sept. 3, 12 Mdt.,	Oct. 1, 12 M., .	+0.508†	10.219†	5.364†	9.711†
Oct. 1, 12 M., .	Oct. 31, 3 A.M.,	+0.298	9.979	5.139	9.681
Oct. 31, 3 A.M.,	Nov. 29, 9 P.M.,	+0.216	9.916	5.066	9.700
Nov. 29, 9 P.M.,	Dec. 29, 4 P.M.,	+0.531	10.102	5.317	9.571
	1903.				
Dec. 29, 4 P.M.,	Jan. 28, 12 M., .	−0.150	9.942	4.896	10.092
Sums, ...		+2.512	120.621	61.570	118.109
Mean of 12 lunar months, referred to Navy Yard base, . . .		+0.209	10.052	5.131	9.842
Corresponding elevations, referred to Boston base, as determined by the Miner bench levels of 1878, .		+0.790	10.630	5.710	9.842

New bench mark { Boston base, ... 15.12
New bench mark { Navy Yard base, ... 14.54

0.58

* Mean of 46 tides. Total during lunation, .57.
† Mean of 47 tides.

Fortunately, we have good independent confirmation of the Navy Yard tide gauges of 1902 in the records of the self-recording gauge maintained by the chief engineer of metropolitan sewers at the Deer Island pumps since 1898, which is tied on to Boston base by levels possessing doubtless all the accuracy of good ordinary bench levels for such important structures. Mr. Brown, chief engineer metropolitan sewers, reports that a brief review of the notes of these levels gives no reason to distrust their precision, but that a careful review will be made at once.

The precision of this apparatus is not quite so good as that at the Navy Yard.

The average mean low water by the recording gauge at the Navy Yard for 1902 was 0.79 above Boston base; the average by the recording gauge at Deer Island for nearly all of the time for the past five years is 0.73 above Boston base.

Mean sea level by the Deer Island gauge for the past five years averages 5.65, Boston base, or only 0.06 foot lower than that determined at the Navy Yard in 1902. Correcting for the rate and time, this difference becomes only .03 foot, — an excellent check. The mean of the entire Deer Island series, July, 1897, to March, 1903: mean high water, 10.58; mean low water, 0.73; mean range, 9.85.

The Coast Survey's twenty-nine-year series does not fall well in line. The group of observations at each one of the many stations occupied by this gauge in its wanderings stands almost by itself. The first group and the last group are apparently the most reliable, and the record as we have it indicates that both are entitled to full credence; and, as previously stated, these do not show any marked subsidence. It is barely possible, but hardly probable, that the idea prevalent at the time, that the dock had settled, led to some unrecorded and misdirected attempt at compensation.

The mean of the Geo. R. Baldwin full series, plotted by a diamond-shaped mark, falls about 2 inches below the straight mean line; but if we omit the gauges of the three winter months, in which there was apparently some trouble with working of gauge, perhaps because of ice, the average shown by the dotted diamond then comes fairly near the straight mean line.

Summing up all of this evidence, I believe that it proves that a subsidence is now or has been recently going on, and that its rate is probably not far from 1 foot per one hundred years; and I trust that the notes above collected and discussed may stimulate more precise records in future by harbor commissions, sewer departments and the United States Coast Survey and city engineers, so that twenty-five or fifty years hence the rate may be established with greater precision.

It also appears wise that a better and more permanent series of standard benches should be established throughout the metropolitan district.

JOHN R. FREEMAN.

NOTE. — The following memoranda were received May 26, 1903, from Louis E. Cutter, C.E.: —

In the Records of the American Academy of Arts and Sciences, three hundred and fourteenth meeting, January, 1849, we find the following note: —

Dr. Jackson (Charles T.) also remarked upon the importance of having permanent marks fixed along our coast, at mean low water, to serve as a future indication in respect to the elevation or subsidence of the land. It was thought that the proper observation might best be made, and the marks fixed, by the United States Coast Survey.

On motion of Dr. Jackson, a committee, consisting of Dr. Jackson, Mr. Desor and Dr. Gay, was appointed "to confer with the proper authorities upon this subject."

Jan. 31, 1849, Davis and Cabot were added to the committee.

Jan. 8, 1850, report, which was recommitted.

This committee reported Feb. 13, 1850, and the corresponding secretary was instructed to forward an authenticated copy to the Secretary of the Treasury.

The report covers about two pages, and recommends that the Secretary of the Treasury be requested to instruct the Superintendent of the Coast Survey to cause tidal observation to be made and monuments established.

May 7, 1850, reply of the Secretary of the Treasury, saying that authority will be given to the Superintendent of the Coast Survey to make observations and communicate results to Academy.

It is a matter of great regret that this valuable suggestion of Dr. Jackson was not more actively followed up.

Another Proof that Boston Base was supposed to be at Mean Low Water.

City Document No. 34, 1850, reports of engineer (Parrott) and of the committee on raising low streets: "Resolved . . . that the grade . . . be . . . fixed and established at a point . . . not lower than 15 feet in height above the plane of mean low water, or the coping of the dry dock in Charlestown."

INDEX.

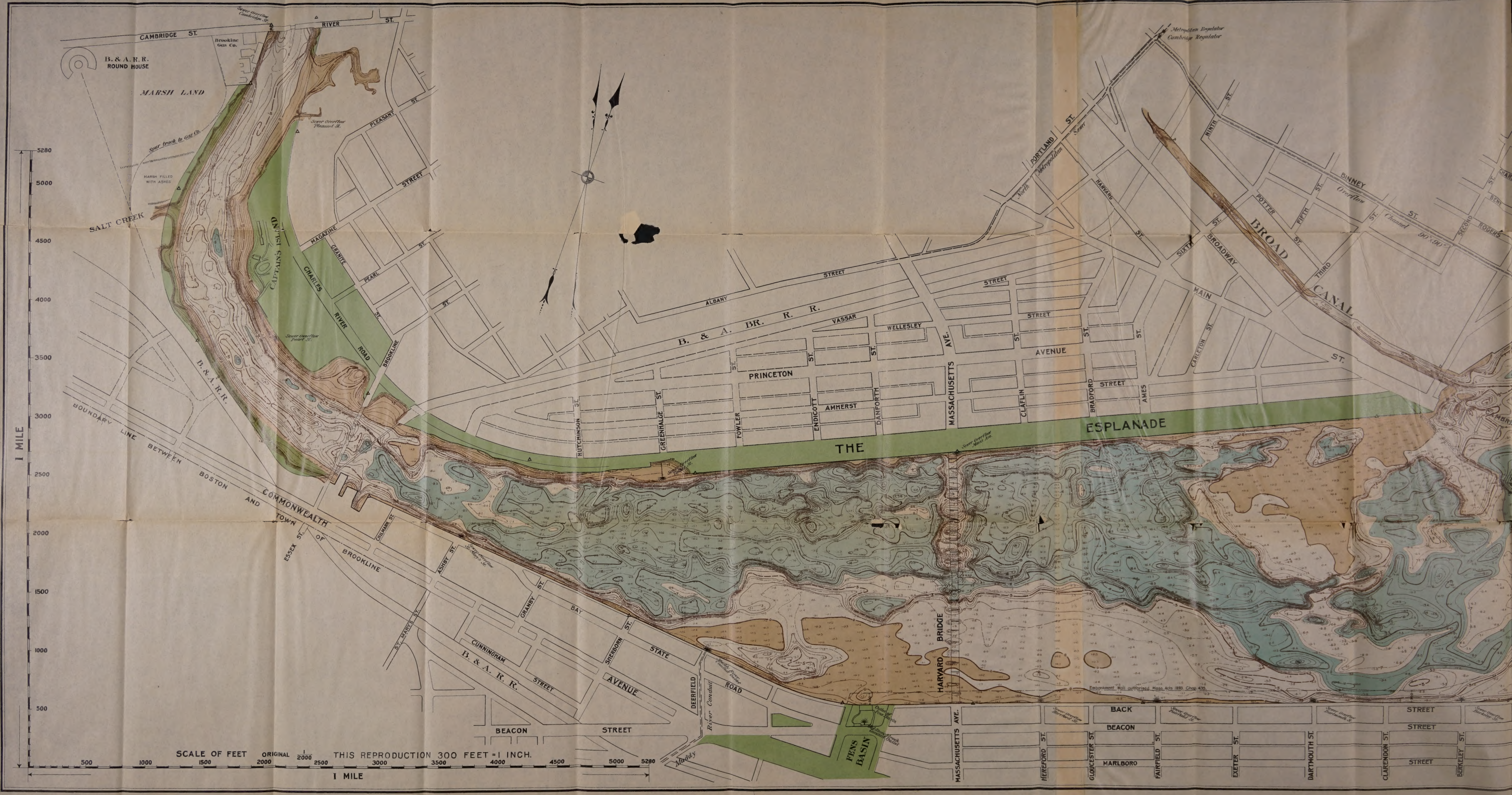
MAP No. 1. Contour Charles River Upper Basin.
Section 1. Watertown Dam to Arsenal St.

MAP No. 2. Section 2. Arsenal St. to
Cambridge-River St.

MAP No. 3. Contour Charles River Lower Basin.
Cambridge-River St. to Craigie Bridge.

THE DATUM PLANE USED FOR CONTOURS AND SOUNDINGS ON THIS MAP IS "BOSTON CITY BASE".
BOSTON CITY BASE IS 0.64 FT. BELOW BASE KNOWN AS "MEAN LOW WATER AT NAVY YARD" WHICH IS THE DATUM USED BY THE U.S COAST SURVEY, THE U.S. ENGINEERS OFFICE AND THE MASS. HARBOR AND LAND COMMISSION
To reduce the elevations given on this map to the mean low water datum, deduct 0.64 feet from the plus heights on this map, and add 0.64 feet to the negative heights on this map.
BROWN AREAS - Flats now exposed with tide at +1.0 - Boston Base. At upper end, water does not drain down to this level between tides.
BLUE AREAS - Have more than 8 Ft. depth with tide at Zero of Boston Base and would have more than 16 Ft. depth with dam as proposed.
GREEN AREAS - Public Parks and Reservations
All soundings located by range and transit intersections.
CHARLES RIVER BASIN
CONTOUR MAP OF UPPER BASIN
FROM SURVEYS AND SOUNDINGS
MADE PRINCIPALLY BY ENGINEERS OF METROPOLITAN PARK COMMISSION FOR
COMMITTEE ON CHARLES RIVER DAM
(APPOINTED RESOLVES 1901, CHAPTER 105)
UNDER SUPERVISION OF
JOHN R. FREEMAN, ENGINEER TO COMMITTEE
OCT., NOV. AND DEC. 1902
WATERTOWN
NEWTON
BOSTON & MAINE R. R.
Fitchburg Div.
BOSTON & ALBANY R. R.
Watertown Sta.
Union Market Sta.
U. S. GOVERNMENT
WATERTOWN ARSENAL
COOKS POND
BRIGHTON
Faneuil Station
ARSENAL ST.
NORTH BEACON ST.
MT. AUBURN ST.
CALIFORNIA ST.
WATERTOWN ST.
CHARLES RIVER ROAD
GALEN ST.
BOYD ST.
MAPLE ST.
WILLIAMS ST.
WATER ST.
CHARLES BANK ROAD
WASHINGTON ST.
RIVERSIDE ST.
BEECHWOOD ST.
SCHOOL ST.
WALNUT ST.
1 MILE
5280
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
SCALE OF FEET ORIGINAL 1:2000 THIS REPRODUCTION 300 FEET = 1 INCH
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5280
1 MILE

C A M B R I D G E
B O S T O N
HARVARD UNIVERSITY
CAMBRIDGE HOSPITAL
MOUNT AUBURN CEMETERY
CAMBRIDGE CEMETERY
LONGFELLOW MEADOW
SOLDIERS FIELD
NORTH BRIGHTON PLAYSTEAD
CHARLES RIVER SPEEDWAY
CHARLES RIVER ROAD
MT. AUBURN ST.
COOLIDGE AVENUE
MASSACHUSETTS AVE.
BOYLSTON ST.
BRATTLE ST.
WESTERN AVENUE
NORTH HARVARD ST.
CAMBRIDGE ST.
RIVER ST.
MARKET ST.
EVERETT ST.
FRANKLIN ST.
ABATTOIR
Brighton Sta.
WELD BOAT CLUB
NEWELL BOAT CLUB
CAMBRIDGE GAS LIGHT CO.
RIVERSIDE PRESS



CAMBRIDGE ST.
RIVER ST.
Brookline Gas Co.
B. & A. R.R. ROUND HOUSE
MARSH LAND
Spur track to Gas Co.
MARSH FILLED WITH ASHES
SALT CREEK
CAPTAIN'S ISLAND
MAGAZINE
GRANITE
PEARL
PLEASANT ST.
STREET
CHARLES RIVER ROAD
BROOKLINE
ALBANY STREET
B. & A. BR. R. R.
VASSAR
WELLESLEY
PRINCETON
AMHERST
STREET
AVENUE
HUTCHINSON ST.
GREENHALGE ST.
FOWLER ST.
ENDICOTT ST.
DANFORTH ST.
MASSACHUSETTS AVE.
CLAFLIN ST.
BRADFORD ST.
AMES ST.
THE ESPLANADE
PORTLAND ST.
North Metropolitan Sewer
Metropolitan Regulator
Cambridge Regulator
HAYWARD ST.
BROADWAY
MAIN
SIXTH
THIRD
POTTER
FIFTH
BINNEY
Overflow Channel
BROAD CANAL
CARLETON ST.
NINTH ST.
SECOND
ROGERS
B. & A. R.R.
BOUNDARY LINE BETWEEN BOSTON AND TOWN OF BROOKLINE
COMMONWEALTH
ESSEX ST.
CHILMARK ST.
ASHBY ST.
ST. MARYS ST.
GRANBY ST.
BAY
SHERBORN ST.
STATE
CUNNINGHAM STREET
B. & A. R. R.
AVENUE
DEERFIELD
ROAD
River Conduit
Muddy
BEACON STREET
FENS BASIN
HARVARD BRIDGE
BACK STREET
BEACON STREET
MARLBORO STREET
MASSACHUSETTS AVE.
HEREFORD ST.
GLOUCESTER ST.
FAIRFIELD ST.
EXETER ST.
DARTMOUTH ST.
CLARENDON ST.
BERKELEY ST.
1 MILE
5280
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
SCALE OF FEET ORIGINAL 1/2000 THIS REPRODUCTION 300 FEET = 1 INCH.
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5280
1 MILE


THE DATUM PLANE USED FOR CONTOURS AND SOUNDINGS ON THIS MAP IS "BOSTON CITY BASE". BOSTON CITY BASE IS 0.64 FT. BELOW THE BASE KNOWN AS "MEAN LOW WATER AT THE NAVY YARD" WHICH IS THE DATUM USED BY THE U.S. COAST SURVEY, THE U.S. ENGINEER OFFICE AND THE MASSACHUSETTS HARBOR AND LAND COMMISSIONERS.
TO REDUCE THE ELEVATIONS GIVEN ON THIS MAP TO THE MEAN LOW WATER DATUM DEDUCT 0.64 FT. FROM THE PLUS HEIGHTS ON THIS MAP AND ADD 0.64 FT. TO THE NEGATIVE HEIGHTS ON THIS MAP.
BROWN AREAS FLATS NOW EXPOSED WITH TIDE AT ZERO BOSTON BASE. (EXTREME LOW WATER UNCOVERS FLATS TO −1.5)
BLUE AREAS HAVE MORE THAN 8 FEET DEPTH WITH TIDE AT ZERO OF BOSTON BASE AND WOULD HAVE MORE THAN 16 FEET DEPTH WITH DAM AS PROPOSED.
GREEN AREAS PUBLIC PARKS AND RESERVATIONS
ALL SOUNDINGS LOCATED BY RANGE AND TRANSIT INTERSECTIONS.
CHARLES RIVER BASIN
CONTOUR MAP OF LOWER BASIN
FROM SURVEYS AND SOUNDINGS
MADE IN AUG. AND SEPT. 1902 FOR
COMMITTEE ON CHARLES RIVER DAM
(APPOINTED RESOLVES 1901, CHAPTER 105.)
UNDER SUPERVISION OF
JOHN R. FREEMAN, ENGINEER TO COMMITTEE.
FIELD WORK PRINCIPALLY BY
G. L. HOSMER, W. E. SPEAR AND C. L. ROOKS, CIVIL ENGINEERS
THE ESPLANADE
CHARLESBANK
BROAD CANAL
LECHMERE CANAL
THE FRONT
CAMBRIDGE BRIDGE
CRAIGIE BRIDGE
HARVARD BRIDGE
FENS BASIN
PUBLIC GARDENS
BOSTON COMMON
BACK STREET
BEACON STREET
MARLBORO STREET
MASSACHUSETTS AVE.
COMMERCIAL AVE.
MAIN ST.
BROADWAY
B. & A. BR. R. R.